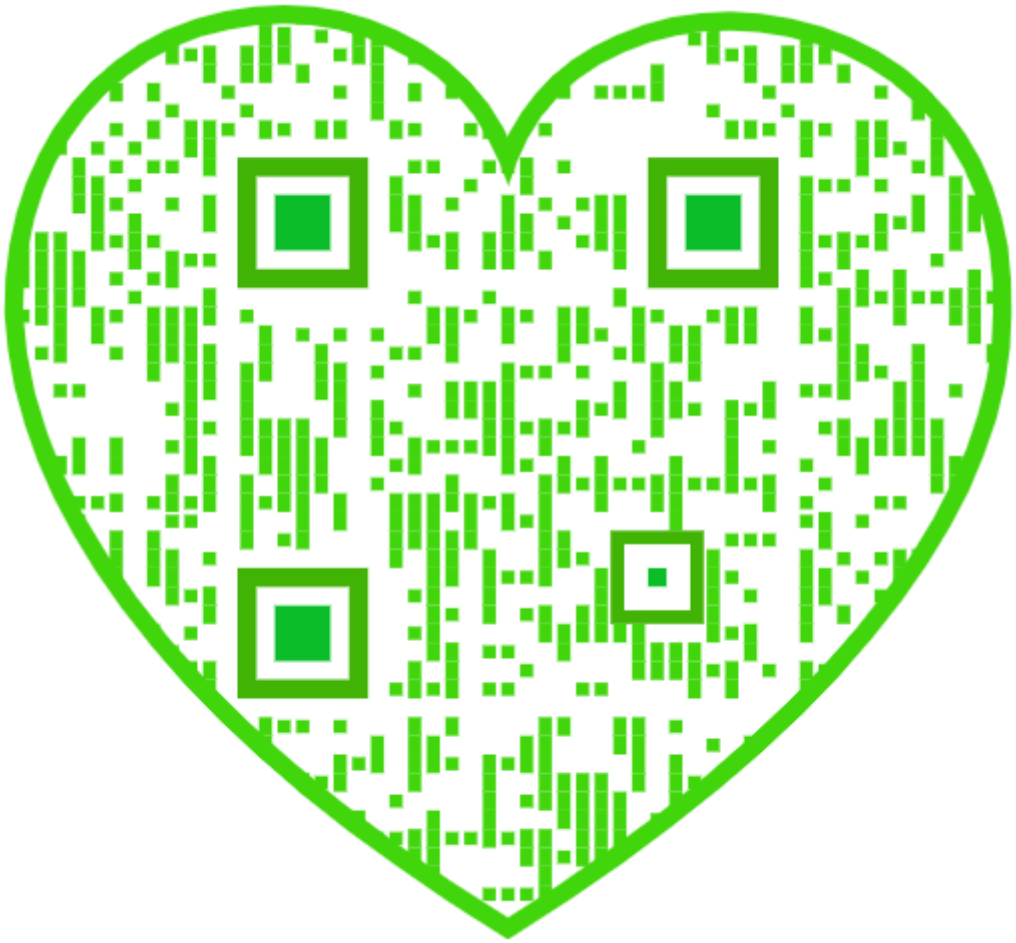


LIBRARY OF CONGRESS
1800

A Skiagraph.

# THE STORY OF ELECTRICITY

BY

JOHN MUNRO

AUTHOR OF

ELECTRICITY AND ITS USES, PIONEERS OF ELECTRICITY, HEROES OF THE TELEGRAPH, ETC., AND JOINT AUTHOR OF MUNRO AND JAMIESON'S POCKET-BOOK OF ELECTRICAL RULES AND TABLES

WITH ONE HUNDRED ILLUSTRATIONS

NEW YORK

MCMXIII

QC 527
.M973
1913

Copyright, 1896, 1902, 1914,
By D. APPLETON AND COMPANY

Printed in the United States of America

$0.50
NOV 21 1914

©CL A388706
no 1

## PUBLISHERS' NOTE.

For our edition of this work the terminology has been altered to conform with American usage, some new matter has been added, and a few of the cuts have been changed and some new ones introduced, in order to adapt the book fully to the practical requirements of American readers.

# CONTENTS.


| CHAPTER | | PAGE |
|---|---|---|
| I. | The Electricity of Friction | 9 |
| II. | The Electricity of Chemistry | 26 |
| III. | The Electricity of Heat | 41 |
| IV. | The Electricity of Magnetism | 45 |
| V. | Electrolysis | 74 |
| VI. | The Telegraph and Telephone | 81 |
| VII. | Electric Light and Heat | 110 |
| VIII. | Electric Power | 124 |
| IX. | Minor Uses of Electricity | 143 |
| X. | The Wireless Telegraph | 174 |
| XI. | Electro-Chemistry and Electro-Metallurgy | 187 |
| XII. | Electric Railways | 201 |
| | List of Books | 213 |
| | Appendix | 215 |
| | Index | 223 |

# LIST OF ILLUSTRATIONS.


| FIGURE | | PAGE |
|---|---|---|
| | A Skiagraph *Frontispiece* | |
| 1 | A Frictional Machine | 11 |
| 2 | | 12 |
| 3 | | 13 |
| 4 | | 14 |
| 5 | | 17 |
| 6 | | 18 |
| 7 | | 19 |
| 8 | The Electrophorus | 20 |
| 9 | The Leyden Jar | 22 |
| 10 | A Wimshurst Machine | 24 |
| 11 | A Voltaic Cell | 28 |
| 12 | | 29 |
| 13 | Cells in Series | 30 |
| 14 | Cells in Parallel | 30 |
| 15 | A Daniell Cell | 33 |
| 16 | The Leclanché Cell | 34 |
| 17 | The Bichromate Cell | 35 |
| 18 | The Chloride of Silver Cell | 35 |
| 19 | The E. C. C. Dry Cell | 37 |
| 20 | The Voltameter | 38 |
| 21 | The E. P. S. Accumulator | 40 |
| 22 | A Thermo-electric Couple | 41 |
| 23 | Thermo-electric Couples in Series | 43 |
| 24 | A Thermo-electric Pile | 44 |
| 25 | A Natural Magnet | 48 |
| 26 | | 50 |
| 27 | | 53 |
| 28 | | 54 |
| 29 | | 55 |
| 30 | The Galvanoscope | 56 |
| 31 | | 57 |
| 32 | | 58 |
| 33 | | 59 |
| 34 | | 60 |
| 35 | | 61 |
| 36 | The Induction Coil | 63 |
| 37 | | 64 |
| 38 | | 65 |
| 39 | | 66 |
| 40 | A Dynamo | 68 |
| 41 | | 70 |
| 42 | | 71 |
| 43 | | 72 |
| 44 | | 78 |
| 45 | | 84 |
| 46 | Morse Signal Alphabet | 87 |
| 47 | A Simple Electro Magnet | 88 |
| 48 | Electro Magnet | 89 |
| 49 | The Morse Instrument | 89 |

| FIGURE | PAGE |
|---|---|
| 50—The Sounder | 90 |
| 51—Sections of the 1894 Atlantic Cable — Actual Sizes— Irish Shore End | 96 |
| Newfoundland Shore End | 97 |
| Deep Sea | 97 |
| Light Intermediate | 97 |
| Heavy Intermediate | 97 |
| 52—The Mirror Instrument | 98 |
| 53 | 99 |
| 54—The Siphon Recorder | 100 |
| 55 | 101 |
| 56—The Telephone | 102 |
| 57—The Microphone | 104 |
| 58 | 106 |
| 59 | 108 |
| 60 | 111 |
| 61—The Pilsen Lamp | 112 |
| 62—The Brush Lamp | 113 |
| 63—The Edison Lamp | 115 |
| 64 | 116 |
| 65 | 116 |
| 66 | 118 |
| 67 | 118 |
| 68 | 119 |
| 69—Electrical Phosphorescence | 120 |
| 70—The Ideal Illuminant | 121 |
| 71 | 122 |
| 72 | 123 |
| 73 | 123 |
| 74 | 123 |
| 75 | 124 |
| 76 | 125 |
| 77—An Electric Railway | 127 |
| 78—An Electric Carriage | 129 |
| 79—An Electric Launch | 130 |
| 80—An Electric Fan | 131 |
| 81—An Electric Sewing Machine | 132 |
| 82—An Electric Drill | 133 |
| 83—An Electric Trembling Bell | 143 |
| 84 | 144 |
| 85 | 145 |
| 86 | 146 |
| 87—A Magneto-Electric Bell | 147 |
| 88 | 148 |
| 89—The Electric "Butterfly" Clock | 151 |
| 90 | 152 |
| 91—The Photophone | 153 |
| 92—The Induction Balance | 155 |
| 93—The Electric Pen | 156 |
| 94—The Phonograph | 159 |
| 95—An Electric Gas Lighter | 160 |
| 96—An Electric Lamp Lighter | 162 |
| 97—An Electric Fuse | 163 |
| 98 | 164 |
| 99 | 165 |
| 100—Photographing the Unseen | 171 |
| 101—Photographing the Skeleton | 172 |
| 102—Marconi's Apparatus | 177 |

# THE STORY OF ELECTRICITY.

## CHAPTER I.

### THE ELECTRICITY OF FRICTION.

A SCHOOLBOY who rubs a stick of sealing-wax on the sleeve of his jacket, then holds it over dusty shreds or bits of straw to see them fly up and cling to the wax, repeats without knowing it the fundamental experiment of electricity. In rubbing the wax on his coat he has electrified it, and the dry dust or bits of wool are attracted to it by reason of a mysterious process which is called "induction."

Electricity, like fire, was probably discovered by some primeval savage. According to Humboldt, the Indians of the Orinoco sometimes amuse themselves by rubbing certain beans to make them attract wisps of the wild cotton, and the custom is doubtless very old. Certainly the ancient Greeks knew that a piece of amber had when rubbed the property of attracting light bodies. Thales of Miletus, wisest of the Seven Sages, and father of Greek philosophy, explained this curious effect by the presence of a "soul" in the amber, whatever he meant by that. Thales flourished 600 years before the Christian era, while Crœsus reigned in Lydia, and Cyrus the Great, in Persia, when the renowned Solon gave

his laws to Athens, and Necos, King of Egypt, made war on Josiah, King of Judah, and after defeating him at Megiddo, dedicated the corslet he had worn during the battle to Apollo Didymæus in the temple of Branchidæ, near Miletus.

Amber, the fossil resin of a pine tree, was found in Sicily, the shores of the Baltic, and other parts of Europe. It was a precious stone then as now, and an article of trade with the Phœnicians, those early merchants of the Mediterranean. The attractive power might enhance the value of the gem in the eyes of the superstitious ancients, but they do not seem to have investigated it, and beyond the speculation of Thales, they have told us nothing more about it.

Towards the end of the sixteenth century Dr. Gilbert of Colchester, physician to Queen Elizabeth, made this property the subject of experiment, and showed that, far from being peculiar to amber, it was possessed by sulphur, wax, glass, and many other bodies which he called *electrics*, from the Greek word *elektron*, signifying amber. This great discovery was the starting-point of the modern science of electricity. That feeble and mysterious force which had been the wonder of the simple and the amusement of the vain could not be slighted any longer as a curious freak of nature, but assuredly none dreamt that a day was dawning in which it would transform the world.

Otto von Guericke, burgomaster of Magdeburg, was the first to invent a machine for exciting the electric power in larger quantities by simply turning a ball of sulphur between the bare hands. Improved by Sir Isaac Newton and others, who employed glass rubbed with silk, it created sparks several inches long. The ordinary fric-

tional machine as now made is illustrated in figure 1, where *P* is a disc of plate glass mounted on a spindle and turned by hand. Rubbers of

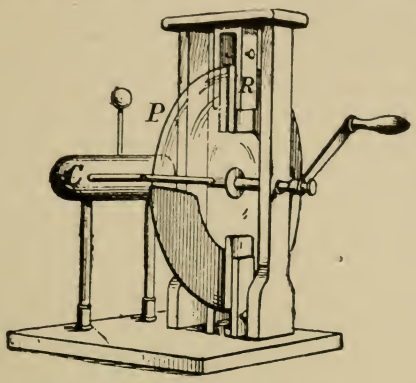



FIG. 1.—A Frictional Machine.

silk *R*, smeared with an amalgam of mercury and tin, to increase their efficiency, press the rim of the plate between them as it revolves, and a brass conductor *C*, insulated on glass posts, is fitted with points like the teeth of a comb, which, as the electrified surface of the plate passes by, collect the electricity and charge the conductor with positive electricity. Machines of this sort have been made with plates 7 feet in diameter, and yielding sparks nearly 2 feet long.

The properties of the "electric fire," as it was now called, were chiefly investigated by Dufay. To refine on the primitive experiment let us replace the shreds by a pithball hung from a support by a silk thread, as in figure 2. If we rub the glass rod vigorously with a silk handkerchief and hold it near, the ball will fly toward the rod.

Similarly we may rub a stick of sealing wax, a bar of sulphur, indeed, a great variety of substances, and by this easy test we shall find them electrified. Glass rubbed with glass will not show any sign of electrification, nor will wax rubbed on wax; but when the rubber is of a different material to the thing rubbed, we shall find, on using proper precautions, that electricity is developed. In fact, the property which was once thought peculiar to amber is found to belong to all bodies. *Any substance, when rubbed with a different substance, becomes electrified.*

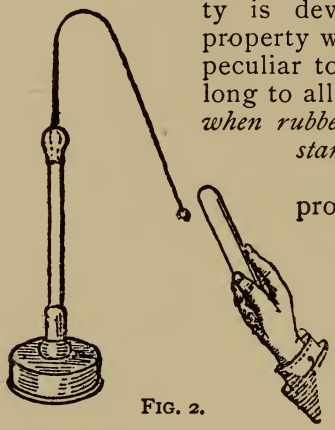


FIG. 2.

The electricity thus produced is termed *frictional* electricity. Of course there are some materials, such as amber, glass, and wax, which display the effect much better than others, and hence its original discovery.

In dry frosty weather the friction of a tortoise-shell comb will electrify the hair and make it cling to the teeth. Sometimes persons emit sparks in pulling off their flannels or silk stockings. The fur of a cat, or even of a garment, stroked in the dark with a warm dry hand will be seen to glow, and perhaps heard to crackle. During winter a person can electrify himself by shuffling in his slippers over the carpet, and light the gas with a spark from his finger. Glass and sealing-wax are, however, the most convenient means for investigating the electricity of friction.

A glass rod when rubbed with a silk handkerchief becomes, as we have seen, highly electric, and will attract a pithball (fig. 2). Moreover, if we substitute the handkerchief for the rod it will also attract the ball (fig. 3). Clearly, then, the handkerchief which rubbed the rod as well as the rod itself is electrified. At first we might suppose that the handkerchief had merely rubbed off some of the electricity from the rod, but a little investigation will soon show that is not the case. If we allow the pithball to touch the glass rod it will steal some of the electricity on the rod, and we shall now find the ball *repelled* by the rod, as illustrated in figure 4. Then, if we withdraw the rod and bring forward the handkerchief, we shall find the ball *attracted* by it. Evidently, therefore, the electricity of the handkerchief is of a different kind from that of the rod.

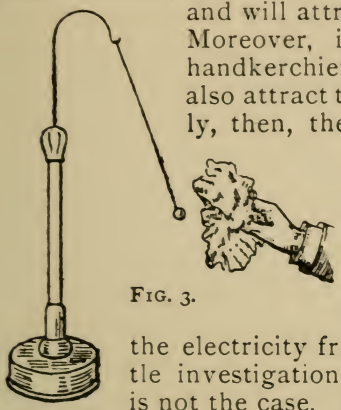


FIG. 3.

Again, if we allow the ball to touch the handkerchief and rub off some of its electricity, the ball will be *repelled* by the handkerchief and *attracted* by the rod. Thus we arrive at the conclusion that whereas the glass rod is charged with one kind of electricity, the handkerchief which rubbed it is charged with another kind, and, judging by their contrary effects on the charged ball or indicator, they are of opposite kinds. To distinguish the two sorts, one is called *positive* and the other *negative* electricity.

Further experiments with other substances will show that sometimes the rod is negative while the rubber is positive. Thus, if we rub the glass rod with cat's fur instead of silk, we shall find the glass negative and the fur positive. Again, if we rub a stick of sealing-wax with the silk handkerchief, we shall find the wax negative and the silk positive. But in every case one is the opposite of the other, and moreover, an equal quantity of both sorts of electricity is developed, one kind on the rod and the other on the rubber. Hence we conclude that *equal and opposite quantities of electricity are simultaneously developed by friction.*

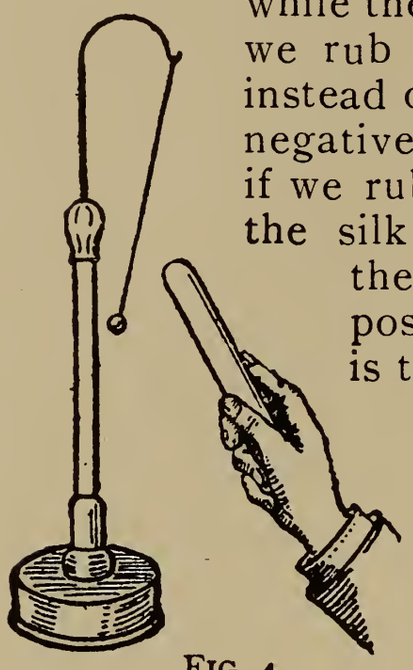


FIG. 4.

If any two of the following materials be rubbed together, that higher in the list becomes positively and the other negatively electrified:—

POSITIVE (+).

Cats' fur.
Polished glass.
Wool.
Cork, at ordinary temperature.
Coarse brown paper.
Cork, heated.
White silk.
Black silk.
Shellac.
Rough glass.

NEGATIVE (—).

The list shows that quality, as well as kind, of material affects the production of electricity. Thus polished glass when rubbed with silk is positive, whereas rough glass is negative. Cork at ordinary temperature is positive when rubbed with hot cork. Black silk is negative to white silk, and it has been observed that the best radiator and absorber of light and heat is the most negative. Black cloth, for instance, is a better radiator than white, hence in the Arctic regions, where the body is much warmer than the surrounding air, many wild animals get a white coat in winter, and in the tropics, where the sunshine is hotter than the body, the European dons a white suit.

The experiments of figures 1, 2, and 3 have also shown us that when the pithball is charged with the positive electricity of the glass rod it is *repelled* by the like charge upon the rod, and *attracted* by the negative or unlike charge on the handkerchief. Again, when it is charged with the negative electricity of the handkerchief it is *repelled* by the like charge on the handkerchief and *attracted* by the positive or unlike charge on the rod. Therefore it is usual to say that *like electricities repel and unlike electricities attract each other.*

We have said that all bodies yield electricity under the friction of dissimilar bodies; but this cannot be proved for every body by simply holding it in one hand and rubbing it with the excitor, as may be done in the case of glass. For instance, if we take a brass rod in the hand and apply the rubber vigorously, it will fail to attract the pithball, for there is no trace of electricity upon it. This is because the metal differs from the glass

in another electrical property, and they must therefore be differently treated. Brass, in fact, is a conductor of electricity and glass is not. In other words, electricity is conducted or led away by brass, so that, as soon as it is generated by the friction, it flows through the hand and body of the experimenter, which are also conductors, and is lost in the ground. Glass on the other hand, is an *insulator*, and the electricity remains on the surface of it. If, however, we attach a glass handle to the rod and hold it by that whilst rubbing it, the electricity cannot then escape to the earth, and the brass rod will attract the pith-ball.

All bodies are conductors of electricity in some degree, but they vary so enormously in this respect that it has been found convenient to divide them into two extreme classes—conductors and insulators. These run into each other through an intermediate group, which are neither good conductors nor good insulators. The following are the chief examples of these classes:—

CONDUCTORS.—All the metals, carbon.

INTERMEDIATE (bad conductors and bad insulators).—Water, aqueous solutions, moist bodies; wood, cotton, hemp, and paper in any but a dry atmosphere; liquid acids, rarefied gases.

INSULATORS.—Paraffin (solid or liquid), ozokerit, turpentine, silk, resin, sealing-wax or shellac, indiarubber, gutta percha, ebonite, ivory, dry wood, dry glass or porcelain, mica, ice, air at ordinary pressures.

It is remarkable that the best conductors of electricity, that is to say, the substances which

offer least resistance to its passage, for instance the metals, are also the best conductors of heat, and that insulators made red hot become conductors. Air is an excellent insulator, and hence we are able to perform our experiments on frictional electricity in it. We can also run bare telegraph wires through it, by taking care to insulate them with glass or porcelain from the w o o d e n poles which support them above the ground. Water, on the other hand, is a partial conductor, and a great enemy to the storage or conveyance of electricity, from its habit of soaking into porous metals, or depositing in a film of dew on the cold surfaces of insulators such as glass, porcelain, or ebonite. The remedy is to exclude it, or keep the insulators warm and dry, or coat them with shellac varnish, wax, or paraffin. Submarine telegraph wires running under the sea are usually insulated from the surrounding water by india-rubber or gutta percha.

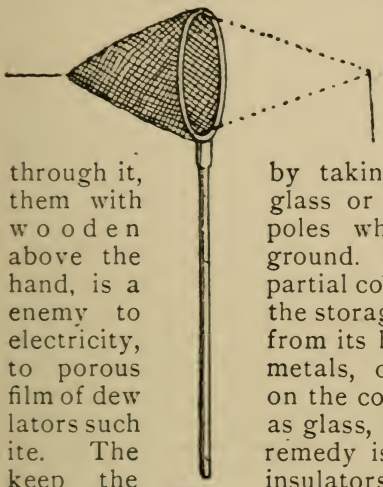


FIG. 5.

The distinction between conductors and non-conductors or insulators was first observed by Stephen Gray, a pensioner of the Charter-house. Gray actually transmitted a charge of electricity along a pack-thread insulated with silk, to a distance of several hundred yards, and thus took an important step in the direction of the electric telegraph.

It has since been found that *frictional electricity appears only on the external surface of conductors.*

This is well shown by a device of Faraday resembling a small butterfly net insulated by a glass handle (fig. 5). If the net be charged it is found that the electrification is only outside, and if it be suddenly drawn outside in, as shown by the dotted line, the electrification is still found outside, proving that the charge has shifted from the inner to the outer surface. In the same way if a hollow conductor is charged with electricity, none is discoverable in the interior. Moreover, its distribution on the exterior is influenced by the shape of the outer surface. On a sphere or ball it is evenly distributed all round, but it accumulates on sharp edges or corners, and most of all on points, from which it is easily discharged.

A neutral body can, as we have seen (fig. 4), be charged by *contact* with an electrified body; but it can also be charged by *induction*, or the influence of the electrified body at a distance.

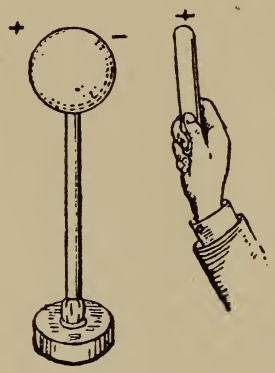



FIG. 6.

Thus if we electrify a glass rod positively (+) and bring it near a neutral or unelectrified brass ball, insulated on a glass support, as in figure 6, we shall find the side of the ball next the rod no longer neutral but negatively electrified (−), and the side away from the rod positively electrified (+).

If we take away the rod again the ball will return to its neutral or non-electric state, showing that the charge was temporarily induced by

the presence of the electrified rod. Again, if, as in figure 7, we have two insulated balls touching each other, and bring the rod up, that nearest the rod will become negative and that farthest from it positive. It appears from these facts that electricity has the power of disturbing or decomposing the neutral state of a neighbouring conductor, and attracting the unlike while it repels the like induced charge. Hence, too, it is that the electrified amber or sealing-wax is able to attract a light straw or pith-ball. The effect supplies a simple way of developing a large amount of electricity from a small initial charge. For if in figure 6 the positive side of the ball be connected for a moment to earth by a conductor, its positive charge will escape, leaving the negative on the ball, and as there is no longer an equal positive charge to recombine with it when the exciting rod is withdrawn, it remains as a negative charge on the ball. Similarly, if we separate the two balls in figure 7, we gain two equal charges—one positive, the other negative. These processes have only to be repeated by a machine in order to develop very strong charges from a feeble source.

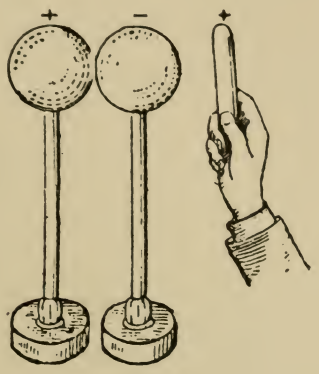


FIG. 7.

Faraday saw that the intervening air played a part in this action at a distance, and proved con-

clusively that the value of the induction depended on the nature of the medium between the induced and the inducing charge. He showed, for example, that the induction through an intervening cake of sulphur is greater than through an equal thickness of air. This property of the medium is termed its *inductive capacity.*

The Electrophorus, or carrier of electricity, is a simple device for developing and conveying a charge on the principle of induction. It consists,

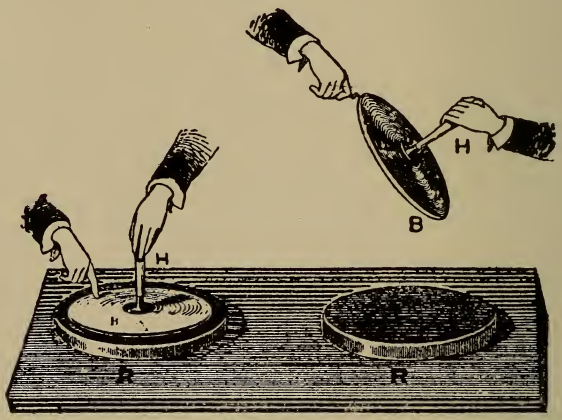



FIG. 8.—The Electrophorus.

as shown in figure 8, of a metal plate *B* having an insulating handle of glass *H*, and a flat cake of resin or ebonite *R*. If the resin is laid on a table and briskly rubbed with cat's fur it becomes negatively electrified. The brass plate is then lifted by the handle and laid upon the cake. It touches the electrified surface at a few points, and takes a minute charge from these by contact.

The rest of it, however, is insulated from the resin by the air. In the main, therefore, the negative charge of the resin is free to induce an opposite or positive charge on the lower surface and a negative charge on the upper surface of the plate. By touching this upper surface with the finger, as shown in figure 8, the negative charge will escape through the body to the ground or "earth," as it is technically called, and the positive charge will remain on the plate. We can withdraw it by lifting the plate, and prove its existence by drawing a spark from it with the knuckle. The process can be repeated as long as the negative charge continues on the resin.

These tiny sparks from the electrophorus, or the bigger discharges of an electrical machine, can be stored in a simple apparatus called a Leyden jar, which was discovered by accident. One day Cuneus, a pupil of Muschenbroeck, professor in the University of Leyden, was trying to charge some water in a glass bottle by connecting it with a chain to the sparkling knob of an electrical machine. Holding the bottle in one hand, he undid the chain with the other, and received a violent shock which cast the bottle on the floor. Muschenbroeck, eager to verify the phenomenon, repeated the experiment, with a still more lively and convincing result. His nerves were shaken for two days, and he afterwards protested that he would not suffer another shock for the whole kingdom of France.

The Leyden jar is illustrated in figure 9, and consists in general of a glass bottle partly coated inside and out with tinfoil *F*, and having a brass knob *K* connecting with its internal coat. When

the charged plate or conductor of the electrophorus touches the knob the inner foil takes a positive charge, which induces a negative charge

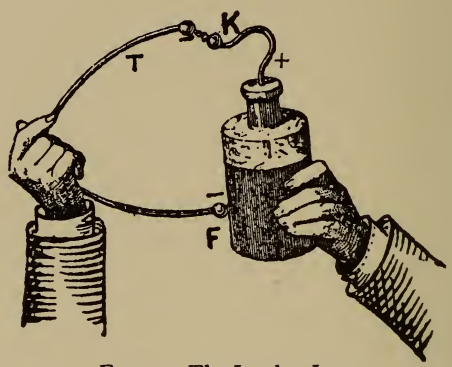



FIG. 9.—The Leyden Jar.

in the outer foil through the glass. The corresponding positive charge induced at the same time escapes through the hand to the ground or "earth." The inner coating is now positively and the outer coating negatively electrified, and these two opposite charges bind or hold each other by mutual attraction. The bottle will therefore continue charged for a long time; in short, until it is purposely discharged or the two electricities combine by leakage over the surface of the glass.

To discharge the jar we need only connect the two foils by a conductor, and thus allow the separated charges to combine. This should be done by joining the *outer* to the *inner* coat with a stout wire, or, better still, the discharging tongs *T*, as shown in the figure. Otherwise, if the

tongs are first applied to the inner coat, the operator will receive the charge through his arms and chest in the manner of Cuneus and Muschenbroeck.

Leyden jars can be connected together in "batteries," so as to give very powerful effects. One method is to join the inner coat of one to the outer coat of the next. This is known as connecting in "series," and gives a very long spark. Another method is to join the inner coat of one to the inner coat of the next, and similarly all the outer coats together. This is called connecting "in parallel," or quantity, and gives a big, but not a long spark.

Of late years the principle of induction, which is the secret of the Leyden jar and electrophorus, has been applied in constructing "influence" machines for generating electricity. Perhaps the most effective of these is the Wimshurst, which we illustrate in figure 10, where *PP* are two circular glass plates which rotate in opposite directions on turning the handle. On the outer rim of each is cemented a row of radial slips of metal at equal intervals. The slips at opposite ends of a diameter are connected together twice during each revolution of the plates by wire brushes *S*, and collecting combs *TT* serve to charge the positive and negative conductors *CC*, which yield very powerful sparks at the knobs *K* above. The given theory of this machine may be open to question, but there can be no doubt of its wonderful performance. A small one produces a violent spark 8 or 10 inches long after a few turns of the handle.

The electricity of friction is so unmanageable that it has not been applied in practice to any

great extent. In 1753 Mr. Charles Morrison, of Greenock, published the first plan of an electric telegraph in the *Scots Magazine*, and proposed to charge an insulated wire at the near end so as to

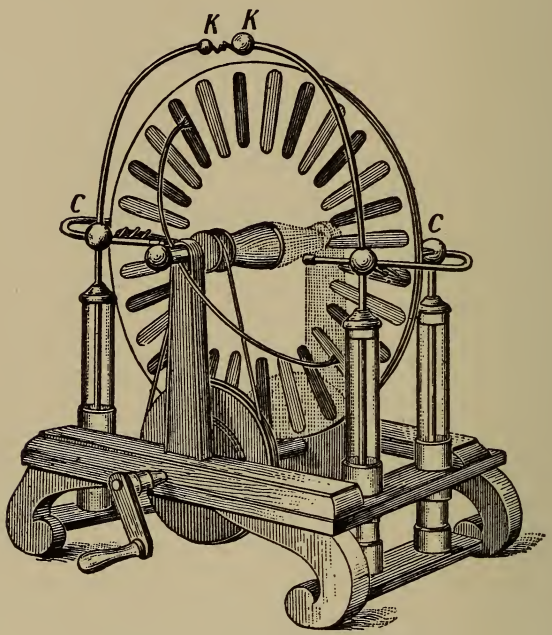



FIG. 10.—A Wimshurst Machine.

make it attract printed letters of the alphabet at the far end. Sir Francis Ronalds also invented a telegraph actuated by this kind of electricity, but neither of these came into use. Morrison, an obscure genius, was before his age, and Ronalds was politely informed by the Government of his

day that "telegraphs of any kind were wholly unnecessary." Little instruments for lighting gas by means of the spark are, however, made, and the noxious fumes of chemical and lead works are condensed and laid by the discharge from the Wimshurst machine. The electricity shed in the air causes the dust and smoke to adhere by induction and settle in flakes upon the sides of the flues. Perhaps the old remark that "smuts" or "blacks" falling to the ground on a sultry day are a sign of thunder is traceable to a similar action.

The most important practical result of the early experiments with frictional electricity was Benjamin Franklin's great discovery of the identity of lightning and the electric spark. One day in June, 1792, he went to the common at Philadelphia and flew a kite beneath a thundercloud, taking care to insulate his body from the cord. After a shower had wetted the string and made it a conductor, he was able to draw sparks from it with a key and to charge a Leyden jar. The man who had "robbed Jupiter of his thunderbolts" became celebrated throughout the world, and lightning rods or conductors for the protection of life and property were soon brought out. These, in their simplest form, are tapes or stranded wires of iron or copper attached to the walls of the building. The lower end of the conductor is soldered to a copper plate buried in the moist subsoil, or, if the ground is rather dry, in a pit containing coke. Sometimes it is merely soldered to the water mains of the house. The upper end rises above the highest chimney, turret, or spire of the edifice, and branches into points tipped with incorrosive metal, such as

platinum. It is usual to connect all the outside metal of the house, such as the gutters and finials to the rod by means of soldered joints, so as to form one continuous metallic network or artery for the discharge.

When a thundercloud charged with electricity passes over the ground, it induces a charge of an opposite kind upon it. The cloud and earth with air between are analogous to the charged foils of the Leyden jar separated by the glass. The two electricities of the jar, we know, attract each other, and if the insulating glass is too weak to hold them asunder, the spark will pierce it. Similarly, if the insulating air cannot resist the attraction between the thundercloud and the earth, it will be ruptured by a flash of lightning. The metal rod, however, tends to allow the two charges of the cloud and earth to combine quietly or to shunt the discharge past the house.

## CHAPTER II.

### THE ELECTRICITY OF CHEMISTRY.

A MORE tractable kind of electricity than that of friction was discovered at the beginning of the present century. The story goes that some edible frogs were skinned to make a soup for Madame Galvani, wife of the professor of anatomy in the University of Bologna, who was in delicate health. As the frogs were lying in the laboratory of the professor they were observed to twitch each time a spark was drawn from an electrical machine that stood by. A similar twitching was

also noticed when the limbs were hung by copper skewers from an iron rail. Galvani thought the spasms were due to electricity in the animal, and produced them at will by touching the nerve of a limb with a rod of zinc, and the muscle with a rod of copper in contact with the zinc. It was proved, however, by Alessandra Volta, professor of physics in the University of Pavia, that the electricity was not in the animal, but generated by the contact of the two dissimilar metals and the moisture of the flesh. Going a step further, in the year 1800 he invented a new source of electricity on this principle, which is known as "Volta's pile." It consists of plates or discs of zinc and copper separated by a wafer of cloth moistened with acidulated water. When the zinc and copper are joined externally by a wire, a *current* of electricity is found in the wire. One pair of plates with the liquid between makes a "couple" or element; and two or more, built one above another in the same order of zinc, copper, zinc, copper, make the pile. The extreme zinc and copper plates, when joined by a wire, are found to deliver a current.

This form of the voltaic, or, as it is sometimes called, galvanic battery, has given place to the "cell" shown in figure 11, where the two plates *Z C* are immersed in acidulated water within the vessel, and connected outside by the wire *W*. The zinc plate has a positive and the copper a negative charge. The positive current flows from the zinc to the copper inside the cell and from the copper to the zinc outside the cell, as shown by the arrows. It thus makes a complete round, which is called the voltaic "circuit," and if the circuit is broken anywhere it will not flow at all.

The positive electricity of the zinc appears to traverse the liquid to the copper, from which it flows through the wire to the zinc. The effect is that the end of the wire attached to the copper is positive (+), and called the positive "pole" or electrode, while the end attached to the zinc is negative (—), and called the negative pole or electrode. "A simple and easy way to avoid confusion as to the direction of the current, is to remember that the *positive* current flows *from* the *copper to* the *zinc* at the point of *metallic* contact."

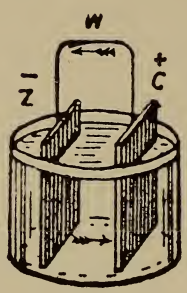



FIG. 11.
A Voltaic Cell.

The generation of this current is accompanied by chemical action in the cell. Experiment shows that the mere *contact* of dissimilar materials, such as copper and zinc, electrifies them—zinc being positive and copper negative; but contact alone does not yield a continuous current of electricity. When we plunge the two metals, still in contact, either directly or through a wire, into water preferably acidulated, a chemical action is set up, the water is decomposed, and the zinc is consumed. Water, as is well known, consists of oxygen and hydrogen. The oxygen combines with the zinc to form oxide of zinc, and the hydrogen is set free as gas at the surface of the copper plate. So long as this process goes on, that is to say, as long as there is zinc and water left, we get an electric current in the circuit. The existence of such a current may be proved by a very simple experiment. Place a penny above and a dime below the tip of the tongue, then bring their edges

into contact, and you will feel an acid taste in the mouth.

Figure 12 illustrates the supposed chemical action in the cell. On the left hand are the

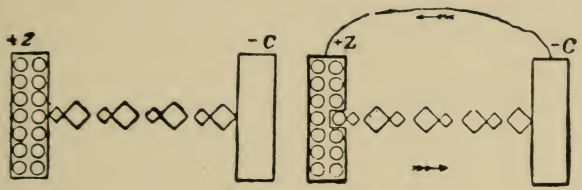



FIG. 12.

zinc and copper plates ($Z\ C$) disconnected in the liquid. The atoms of zinc are shown by small circles; the molecules of water, that is, oxygen, and hydrogen ($H_2\ O$) by lozenges of unequal size. On the right hand the plates are connected by a wire outside the cell; the current starts, and the chemical action begins. An atom of zinc unites with an atom of oxygen, leaving two atoms of hydrogen thus set free to combine with another atom of oxygen, which in turn frees two atoms of hydrogen. This interchange of atoms goes on until the two atoms of hydrogen which are freed last abide on the surface of the copper. The "contact electricity" of the zinc and copper probably begins the process, and the chemical action keeps it up. Oxygen, being an "electro-negative" element in chemistry, is attracted to the zinc, and hydrogen, being "electro-positive," is attracted to the copper.

The difference of electrical condition or "potential" between the plates by which the current is started has been called the *electromotive force*, or force which puts the electricity in motion. The

obstruction or hindrance which the electricity overcomes in passing through its conductor is known as the *resistance.* Obviously the higher the electromotive force and the lower the resistance, the stronger will be the current in the conductor. Hence it is desirable to have a cell which will give a high electromotive force and a low internal resistance.

Voltaic cells are grouped together in the mode of Leyden jars. Figure 13 shows how they are

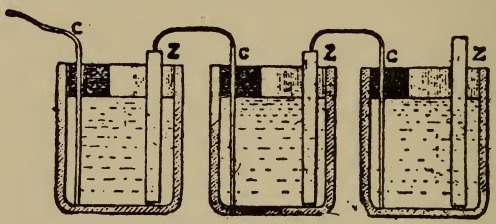



FIG. 13.—Cells in Series.

joined "in series," the zinc or negative pole of one being connected by wire to the copper or positive pole of the next. This arrangement mul-

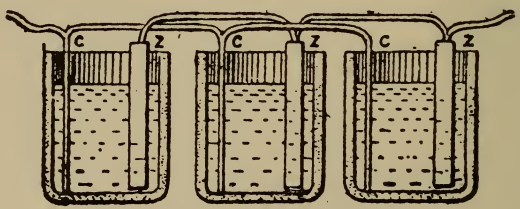



FIG. 14.—Cells in Parallel.

tiplies alike the electromotive force and the resistance. The electromotive force of the battery is the sum of the electromotive forces of all the

cells, and the resistance of the battery is the sum of the resistances of all the cells. High electromotive forces or "pressures" capable of overcoming high resistances outside the battery can be obtained in this way.

Figure 14 shows how the zincs are joined "in parallel," the zinc or negative pole of one being connected by wire to the zinc or negative pole of the rest, and all the copper or positive poles together. This arrangement does not increase the electromotive force, but diminishes the resistance. In fact, the battery is equivalent to a single cell having plates equal in area to the total area of all the plates. Although unable to overcome a high resistance, it can produce a large volume or quantity of electricity.

Numerous voltaic combinations and varieties of cell have been found out. In general, wherever two metals in contact are placed in a liquid which acts with more chemical energy on one than on the other, as sulphuric acid does on zinc in preference to copper, there is a development of electricity. Readers may have seen how an iron fence post corrodes at its junction with the lead that fixes it in the stone. This decay is owing to the wet forming a voltaic couple with the two dissimilar metals and rusting the iron. In the following list of materials, when any two in contact are plunged in dilute acid, that which is higher in the order becomes the positive plate or negative pole to that which is lower:—

| | | |
|---|---|---|
| POSITIVE. | Iron. | Silver. |
| Zinc. | Nickel. | Gold. |
| Cadmium. | Bismuth. | Platinum. |
| Tin. | Antimony. | Graphite. |
| Lead. | Copper. | NEGATIVE. |

There being no chemical union between the hydrogen and copper in the zinc and copper couple, that gas accumulates on the surface of the copper plate, or is liberated in bubbles. Now, hydrogen is positive compared with copper, hence they tend to oppose each other in the combination. The hydrogen diminishes the value of the copper, the current grows weaker, and the cell is said to "polarise." It follows that a simple water cell is not a good arrangement for the supply of a steady current.

The Daniell cell is one of the best, and gives a very constant current. In this battery the copper plate is surrounded by a solution of sulphate of copper ($Cu\,SO_4$), which the hydrogen decomposes, forming sulphuric acid ($H_2SO_4$), thus taking itself out of the way, and leaving pure copper ($Cu$) to be deposited as a fresh surface on the copper plate. A further improvement is made in the cell by surrounding the zinc plate with a solution of sulphate of zinc ($Zn\,SO_4$), which is a good conductor. Now, when the oxide of zinc is formed by the oxygen uniting with the zinc, the free sulphuric acid combines with it, forming more sulphate of zinc, and maintaining the *conductivity* of the cell. It is only necessary to keep up the supply of zinc, water, and sulphate of copper to procure a steady current of electricity.

The Daniell cell is constructed in various ways. In the earlier models the two plates with their solutions were separated by a porous jar or partition, which allowed the solutions to meet without mixing, and the current to pass. Sawdust moistened with the solutions is sometimes used for this porous separator, for instance, on board ships for laying submarine cables,

where the rolling of the waves would blend the liquids.

In the "gravity" Daniell the solutions are kept apart by their specific gravities, yet mingle by slow diffusion. Figure 15 illustrates this common type of cell, where *Z* is the zinc plate in a solution of sulphate of zinc, and *C* is the copper plate in a solution of sulphate of copper, fed by crystals of the "blue vitriol." The wires to connect the plates are shown at *W W*. It should be noticed that the zinc is cast like a wheel to expose a larger surface to oxidation, and to reduce the resistance of the cell, thus increasing the yield of current. The extent of surface is not so important in the case of the copper plate, which is not acted on, and in this case is merely a spiral of wire, helping to keep the solutions apart and the crystals down. The Daniell cell is much employed in telegraphy. The Bunsen cell consists of a zinc plate in sulphuric acid, and a carbon plate in nitric acid, with a porous separator between the liquids. During the action of the cell, hydrogen, which is liberated at the carbon plate, is removed by combining with the nitric acid. The Grove cell is a modification of the Bunsen, with platinum instead of carbon. The Smee cell is a zinc plate side by side with a "platinised" silver plate in dilute sulphuric acid. The silver

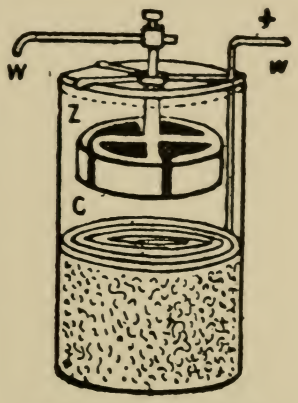



FIG. 15.—A Daniell Cell.

is coated with rough platinum to increase the surface and help to dislodge the hydrogen as bubbles and keep it from polarising the cell. The Bunsen, Grove, and Smee batteries are, however, more used in the laboratory than elsewhere.

The Leclanché is a fairly constant cell, which requires little attention. It "polarises" in action but soon regains its normal strength when allowed to rest, and hence it is useful for working electric bells and telephones. As shown in figure 16, it consists of a zinc rod with its connecting wire *Z*, and a carbon plate *C* with its binding screw, between two cakes *M M* of a mixture of black oxide of manganese, sulphur, and carbon, plunged in a solution of sal ammoniac. The oxide of manganese relieves the carbon plate of its hydrogen. The strength of the solution is maintained by spare crystals of sal ammoniac lying on the bottom of the cell, which is closed to prevent evaporation, but has a venthole for the escape of gas.

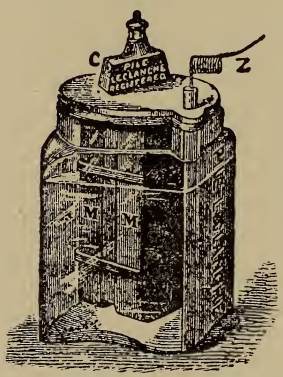



FIG. 16.—The Leclanché Cell.

The Bichromate of Potash cell polarises more than the Leclanché, but yields a more powerful current for a short time. It consists, as shown in figure 17, of a zinc plate *Z* between two carbon plates *C C* immersed in a solution of bichromate of potash, sulphuric acid (vitriol), and water. The zinc is always lifted out of the solution when the cell is not in use. The gas which collects in the

carbons, and weakens the cell, can be set free by raising the plates out of the liquid when the cell is not wanted. Stirring the solution has a similar effect, and sometimes the constancy of the cell is maintained by a circulation of the liquid. In Fuller's bichromate cell the zinc is amalgamated with mercury, which is kept in a pool beside it by means of a porous pot.

De la Rue's chloride of silver cell (fig. 18) is, from its constancy and small size, well adapted for medical and testing purposes. The "plates" are a little rod or pencil of zinc *Z*, and a strip or wire of silver *S*, coated with chloride of silver and sheathed in parchment paper. They are plunged in a solution of ammonium chloride *A*, contained in a glass phial or beaker, which is closed to suppress evaporation. A tray form of the cell is also made by laying a sheet of silver foil on the bottom of the shallow jar, and strewing it with dry chloride of silver, on which is laid a jelly to support the zinc plate. The jelly is prepared by mixing a solution of chloride of ammonium with "agar-agar," or Ceylon moss. This type permits the use of larger plates, and adapts the battery for lighting small electric lamps.

FIG. 17.—The Bichromate Cell.

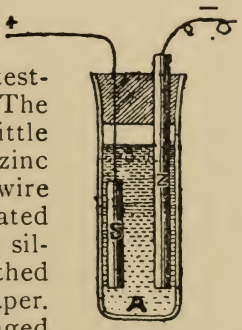



FIG. 18. The Chloride of Silver Cell.

Skrivanoff has modified the De la Rue cell by substituting a solution of caustic potash for the ammonium chloride, and his battery has been used for "star" lights, that is to say, the tiny electric lamps of the ballet. The Schanschieff battery, consisting of zinc and carbon plates in a solution of basic sulphate of mercury, is suitable for reading, mining, and other portable lamps.

The Latimer Clark "standard" cell is used by electricians in testing, as a constant electromotive force. It consists of a pure zinc plate separated from a pool of mercury by a paste of mercurous proto-sulphate and saturated solution of sulphate of zinc. Platinum wires connect with the zinc and mercury and form the poles of the battery, and the mouth of the glass cell is plugged with solid paraffin. As it is apt to polarise, the cell must not be employed to yield a current, and otherwise much care should be taken of it.

Dry cells are more cleanly and portable than wet, they require little or no attention, and are well suited for household or medical purposes. The zinc plate forms the vessel containing the carbon plate and chemical reagents. Figure 19 represents a section of the "E. C. C." variety, where *Z* is the zinc standing on an insulating sole *I*, and fitted with a connecting wire or terminal *T* (−), which is the negative pole. The carbon *C* is embedded in black paste *M*, chiefly composed of manganese dioxide, and has a binding screw or terminal *T* (+), which is the positive pole. The black paste is surrounded by a white paste *L*, consisting mainly of lime and sal-ammoniac. There is a layer of silicate cotton *S C* above the paste, and the mouth is sealed with

black pitch *P*, through which a waste-tube *W T* allows the gas to escape.

The Hellesen dry cell is like the "E. C. C.," but contains a hollow carbon, and is packed with sawdust in a millboard case. The Leclanché-Barbier dry cell is a modification of the Leclanché wet cell, having a paste of sal-ammoniac instead of a solution.

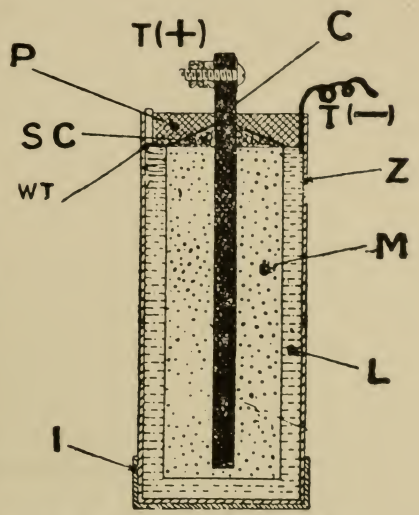



FIG. 19.—The E. C. C. Dry Cell.

All the foregoing cells are called "primary," because they are generators of electricity. There are, however, batteries known as "secondary," which store the current as the Leyden jar stores up the discharge from an electrical machine.

In the action of a primary cell, as we have seen, water is split into its constituent gases, oxygen and hydrogen. Moreover, it was discovered by Carlisle and Nicholson in the year 1800 that the current of a battery could decompose water in the outer part of the circuit. Their experiment is usually performed by the apparatus shown in figure 20, which is termed a

voltameter, and consists of a glass vessel *V*, containing water acidulated with a little sulphuric acid to render it a better conductor, and two glass test-tubes *OH* inverted over two platinum strips or electrodes, which rise up from the bottom of the vessel and are connected underneath it to wires from the positive and negative poles of the battery *C Z*. It will be understood that the cur-

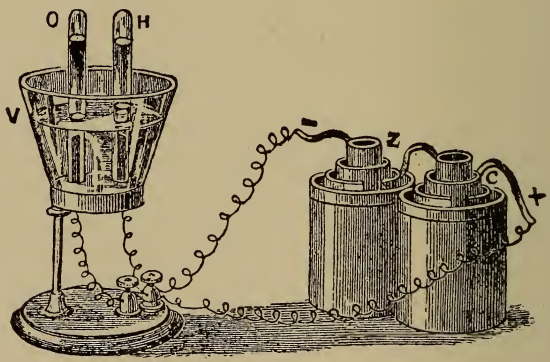



FIG. 20.—The Voltameter.

rent enters the water by the positive electrode, and leaves it by the negative electrode.

When the power of the battery is sufficient the water in the vessel is decomposed, and oxygen being the negative element, collects at the positive foil or electrode, which is covered by the tube *O*. The hydrogen, on the other hand, being positive, collects at the negative foil under the tube *H*. These facts can be proved by dipping a red-hot wick or taper into the gas of the tube *O* and seeing it blaze in presence of the oxygen which feeds the combustion, then dipping the

lighted taper into the gas of the tube *H* and watching it burn with the blue flame of hydrogen. The volume of gas at the *cathode* or negative electrode is always twice that at the *anode* or positive electrode, as it should be according to the known composition of water.

Now, if we disconnect the battery and join the two platinum electrodes of the voltameter by a wire, we shall find a current flowing out of the voltameter as though it were a battery, but in the reverse direction to the original current which decomposed the water. This "secondary" or reacting current is evidently due to the polarisation" of the foils—that is to say, the electro-positive and electro-negative gases collected on them.

Professor Groves constructed a gas battery on this principle, the plates being of platinum and the two gases surrounding them oxygen and hydrogen, but the most useful development of it is the accumulator or storage battery.

The first practicable secondary battery of Gaston Planté was made of sheet lead plates or electrodes, kept apart by linen cloth soaked in dilute sulphuric acid, after the manner of Volta's pile. It was "charged" by connecting the plates to a primary battery, and peroxide of lead ($Pb\ O_2$) was formed on one plate and spongy lead ($Pb$) on the other. When the charging current was cut off the peroxide plate became the positive and the spongy plate the negative pole of the secondary cell.

Faure improved the Planté cell by adding a paste of red lead or minium ($Pb_2\ O_4$) and dilute sulphuric acid ($H_2\ SO_4$), by which a large quantity of peroxide and spongy lead could be formed

on the plates. Sellon and Volckmar increased its efficiency by putting the paste into holes cast in the lead. The "E. P. S." accumulator of the Electrical Power Storage Company is illustrated in figure 21, and consists of a glass or teak box

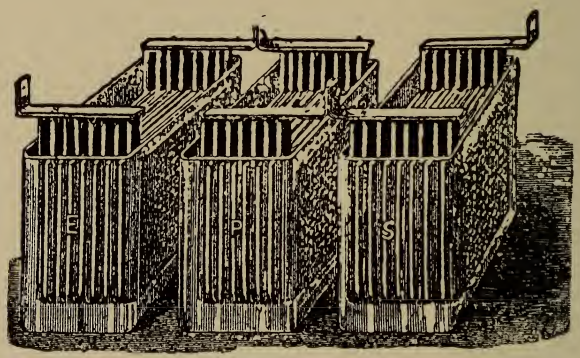



FIG. 21.—The E. P. S. Accumulator.

containing two sets of leaden grids perforated with holes, which are primed with the paste and steeped in dilute sulphuric acid. Alternate grids are joined to the poles of a charging battery or generator, those connected to the positive pole being converted into peroxide of lead and the others into spongy lead. The terminal of the peroxide plates, being the positive pole of the accumulator, is painted red, and that of the spongy plates or negative pole black. Accumulators of this kind are highly useful as reservoirs of electricity for maintaining the electric light, or working electric motors in tramcars, boats, and other carriages.

## CHAPTER III.

### THE ELECTRICITY OF HEAT.

In the year 1821 Professor Seebeck, of Berlin, discovered a third source of electricity. Volta had found that two dissimilar metals in contact will produce a current by chemical action, and Seebeck showed that heat might take the place of chemical action. Thus, if a bar of antimony *A* (fig. 22) and a bar of bismuth *B* are in contact at one end, and the junction is heated by a spirit lamp to a higher temperature than the rest of the bars, a difference in their electric state or potential will be set up, and if the other ends are joined by a wire *W*, a current will flow through the wire. The direction of the current, indicated by the arrow, is from the bismuth to the antimony across the joint, and from the antimony to the bismuth through the external wire. This combination, which is called a "thermo-electric couple," is clearly analogous to the voltaic couple, with heat in place of chemical affinity. The direction of the current within and without the couple shows that the bismuth is positive to the antimony. This property of generating a current of electricity by contact under the influence of heat is not confined to bismuth and antimony, or even to the metals, but is common to all dissimilar substances in their degree. In the following list of bodies each is positive to those beneath it,

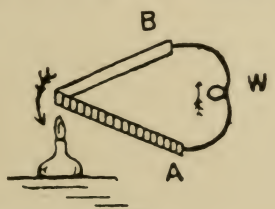



FIG. 22.
A Thermo-electric Couple.

negative to those above it, and the further apart any two are in the scale the greater the effect. Thus bismuth and antimony give a much stronger current with the same heating than copper and iron. Bismuth and selenium produce the best result, but selenium is expensive and not easy to manipulate. Copper and German silver will make a cheap experimental couple:—

POSITIVE.
Bismuth.
Cobalt.
Potassium.
Nickel.
Sodium.
Lead.
Tin.
Copper.
Platinum.
Silver.
Zinc.
Cadmium.
Arsenic.
Iron.
Red phosphorus.
Antimony.
Tellurium.
Selenium.
NEGATIVE.

Other things being equal, the hotter the joint in comparison with the free ends of the bars the stronger the current of electricity. Within certain limits the current is, in fact, proportional to this difference of temperature. It always flows in the same direction if the joint is not overheated, or, in other words, raised above a certain temperature.

The electromotive force and current of a thermo-electric couple is very much smaller than that given by an ordinary voltaic cell. We can, however, multiply the effect by connecting a number of pairs together, and so forming a pile or battery. Thus figure 23 shows three couples joined "in series," the positive pole of one being connected to the negative pole of the next. Now, if all the junctions on the left are hot and those on the right are cool, we will get the united effect of the whole, and the total current will flow through the wire *W*, joining the extreme bars or positive and negative poles of the battery. It must be borne in mind that although the bismuth and antimony of this thermo-electric battery, like the zinc and copper of the voltaic or chemico-electric battery, are respectively positive and negative to each other, the poles or wires attached to these metals are, on the contrary, negative and positive. This peculiarity arises from the current starting between the bismuth and antimony at the heated junction.

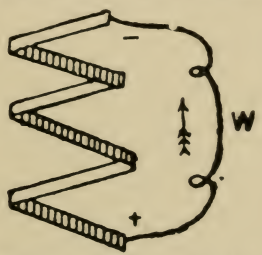



FIG. 23.—Thermo-electric Couples in Series.

The internal resistance of a "thermo-electric pile" is, of course, very slight, the metals being good conductors, and this fact gives it a certain advantage over the voltaic battery. Moreover, it is cleaner and less troublesome than the chemical battery, for it is only necessary to keep up the required difference of temperature between the hot and cold junctions in order to get a

steady current. No solutions or salts are required, and there appears to be little or no waste of the metals. It is important, however, to avoid sudden heating and cooling of the joints, as this tends to destroy them.

Clammond, Gülcher, and others have constructed useful thermo-piles for practical purposes. Figure 24 illustrates a Clammond thermo-pile of 75 couples or elements. The metals forming these pairs are an alloy of bismuth and antimony for one and iron for the other. Prisms of the alloy are cast on strips of iron to form the junctions. They are bent in rings, the junctions in a series making a zig-zag round the circle. The rings are built one over the other in a cylinder of couples, and the inner junctions are heated by a Bunsen gas-burner in the hollow core of the battery. A gas-pipe seen in front leads to the burner, and the wires *W W* connected to the extreme bars or poles are the electrodes of the pile.

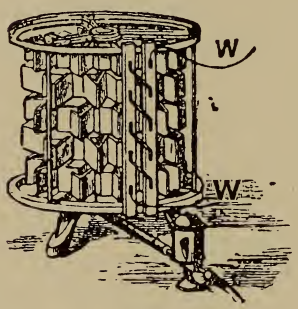



FIG. 24.
A Thermo-electric Pile.

Thermo-piles are interesting from a scientific point of view as a direct means of transforming heat into electricity. A sensitive pile is also a delicate detector of heat by virtue of the current set up, which can be measured with a galvanometer or current meter. Piles of antimony and bismuth are made which can indicate the heat of a lighted match at a distance of several

yards, and even the radiation from certain of the stars.

Thermo-batteries have been used in France for working telegraphs, and they are capable of supplying small installations of the electric light or electric motors for domestic purposes.

The action of the thermo-pile, like that of a voltaic cell, can be reversed. By sending a current through the couple from the antimony to the bismuth we shall find the junction *cooled*. This "Peltier effect," as it is termed, after its discoverer, has been known to freeze water, but no practical application has been made of it.

A very feeble thermo-electric effect can be produced by heating the junction of two different pieces of the same substance, or even by making one part of the same conductor hotter than another. Thus a sensitive galvanometer will show a weak current if a copper wire connected in circuit with it be warmed at one point. Moreover, it has been found by Lord Kelvin that if an iron wire is heated at any point, and an electric current be passed through it, the hot point will shift along the wire in a direction contrary to that of the current.

## CHAPTER IV.

### THE ELECTRICITY OF MAGNETISM.

We have already seen how electricity was first produced by the simple method of rubbing one body on another, then by the less obvious means of chemical union, and next by the finer agency

of heat. In all these, it will be observed, a substantial contact is necessary. We have now to consider a still more subtle process of generation, not requiring actual contact, which, as might be expected, was discovered later, that, mainly through the medium of magnetism.

The curious mineral which has the property of attracting iron was known to the Chinese several thousand years ago, and certainly to the Greeks in the times of Thales, who, as in the case of the rubbed amber, ascribed the property to its possession of a soul.

Lodestone, a magnetic oxide of iron ($Fe_3 O_4$), is found in various parts of China, especially at T'szchou in Southern Chihli, which was formerly known as the "City of the Magnet." It was called by the Chinese the love-stone or *thsu-chy*, and the stone that snatches iron or *ny-thy-chy*, and perchance its property of pointing out the north and south direction was discovered by dropping a light piece of the stone, if not a sewing needle made of it, on the surface of still water. At all events, we read in Père Du Halde's *Description de la Chine*, that sometime in or about the year 2635 B. C. the great Emperor Hoang-ti, having lost his way in a fog whilst pursuing the rebellious Prince Tchiyeou on the plains of Tchou-lou, constructed a chariot which showed the cardinal points, thus enabling him to overtake and put the prince to death.

A magnetic car preceded the Emperors of China in ceremonies of state during the fourth century of our era. It contained a genius in a feather dress who pointed to the south, and was doubtless moved by a magnet floating in water or turning on a pivot. This rude appliance was

afterwards refined into the needle compass for guiding mariners on the sea, and assisting the professors of feng-shui or geomancy in their magic rites.

Magnetite was also found at Heraclea in Lydia, and at Magnesium on the Meander or Magnesium at Sipylos, all in Asia Minor. It was called the "Heraclean Stone" by the people, but came at length to bear the name of "Magnet" after the city of Magnesia or the mythical shepherd Magnes, who was said to have discovered it by the attraction of his iron crook.

The ancients knew that it had the power of communicating its attractive property to iron, for we read in Plato's "Ion" that a number of iron rings can be supported in a chain by the Heraclean Stone. Lucretius also describes an experiment in which iron filings are made to rise up and "rave" in a brass basin by a magnet held underneath. We are told by other writers that images of the gods and goddesses were suspended in the air by lodestone in the ceilings of the temples of Diana of Ephesus, of Serapis at Alexandria, and others. It is surprising, however, that neither the Greeks nor Romans, with all their philosophy, would seem to have discovered its directive property.

During the dark ages pieces of lodestone mounted as magnets were employed in the "black arts." A small natural magnet of this kind is shown in figure 25, where *L* is the stone shod with two iron "pole-pieces," which are joined by a "keeper" *A* or separable bridge of iron carrying a hook for supporting weights.

Apparently it was not until the twelfth century that the compass found its way into Europe

from the East. In the Landnámmabok of Ari Frode, the Norse historian, we read that Flocke Vildergersen, a renowned viking, sailed from Norway to discover Iceland in the year 868, and took with him two ravens as guides, for in those days the "seamen had no lodestone (that is, no lidar stein, or leading stone) in the northern countries." The *Bible*, a poem of Guiot de Provins, minstrel at the court of Barbarossa, which was written in or about the year 1190, contains the first mention of the magnet in the West. Guiot relates how mariners have an "art which cannot deceive" of finding the position of the polestar, that does not move. After touching a needle with the magnet, "an ugly brown stone which draws iron to itself," he says they put the needle on a straw and float it on water so that its point turns to the hidden star, and enables them to keep their course. Arab traders had probably borrowed the floating needle from the Chinese, for Bailak Kibdjaki, author of the *Merchant's Treasure*, written in the thirteenth century, speaks of its use in the Syrian sea. The first Crusaders were probably instrumental in bringing it to France, at all events Jacobus de Vitry (1204–15) and Vincent de Beauvais (1250) mention its use, De Beauvais calling the poles of the needle by the Arab words *aphron* and *zohron*.

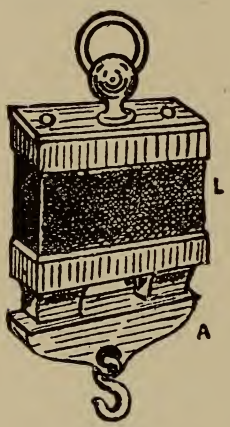



FIG. 25.
A Natural Magnet.

Ere long the needle was mounted on a pivot and provided with a moving card showing the principal directions. The variation of the needle from the true north and south was certainly known in China during the twelfth, and in Europe during the thirteenth century. Columbus also found that the variation changed its value as he sailed towards America on his memorable voyage of 1492. Moreover, in 1576, Norman, a compass maker in London, showed that the north-seeking end of the needle dipped below the horizontal.

In these early days it was supposed that lodestone in the pole-star, that is to say, the "lodestar" of the poets or in mountains of the far north, attracted the trembling needle; but in the year 1600, Dr. Gilbert, the founder of electric science, demonstrated beyond a doubt that the whole earth was a great magnet. A magnet, as is well known, has, like an electric battery, always two poles or centres of attraction, which are situated near its extremities. Sometimes, indeed, when the magnet is imperfect, there are "consequent poles" of weaker force between them. One of the poles is called the "north," and the other the "south," because if the magnet were freely pivotted like a compass needle, the former would turn to the north and the latter to the south.

Either pole will attract iron, but soft or annealed iron does not retain the magnetism nearly so well as steel. Hence a boy's test for the steel of his knife is only efficacious when the blade itself becomes magnetic after being touched with the magnet. A piece of steel is readily magnetised by stroking it from end to end in one direction with the pole of a magnet, and in this way

compass needles and powerful bar magnets can be made.

The poles attract iron at a distance by "induction," just as a charge of electricity, be it positive or negative, will attract a neutral pith ball; and Dr. Gilbert showed that a north pole always repels another north pole and attracts a south pole, while, on the other hand, a south pole always repels a south pole and attracts a north pole. This can be proved by suspending a magnetic needle like a pithball, and approaching another towards it, as illustrated in figure 26, where the north pole *N* attracts the south *S*. Obviously there are two opposite kinds of magnetic poles, as of electricity, which always appear together, and *like magnetic poles repel, unlike magnetic poles attract each other.*

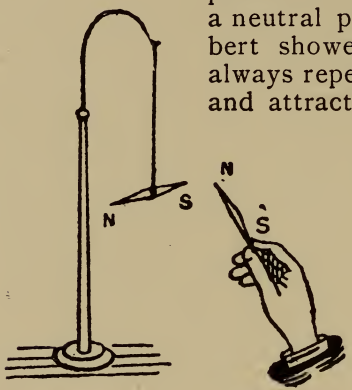



FIG. 26.

It follows that the magnetic pole of the compass needle which turns to the north must be unlike the north and like the south magnetic pole of the earth. Instead of calling it the "north," it would be less confusing to call it the "north-seeking" pole of the needle.

Gilbert made a "terella," or miniature of the earth, as a magnet, and not only demonstrated how the compass needle sets along the lines joining the north and south magnetic poles, but

explained the variation and the dip. He imagined that the magnetic poles coincided with the geographical poles, but, as a matter of fact, they do not, and, moreover, they are slowly moving round the geographical poles, hence the *declination* of the needle, that is to say its angle of divergence from the true meridian or north and south line, is gradually changing. The north magnetic pole of the earth was actually discovered by Sir John Ross north of British America, on the coast of Boothia (latitude 70° 5′ N., longitude 96° 46′ W.), where, as foreseen, the needle entirely lost its directive property and stood upright, or, so to speak, on its head. The south magnetic pole lies in the Prince Albert range of Victoria Land, and was almost reached by Sir James Clark Ross.

The magnetism of the earth is such as might be produced by a powerful magnet inside, but its origin is unknown, although there is reason to believe that masses of lodestone or magnetic iron exist in the crust. Coulomb found that not only iron, but all substances are more or less magnetic, and Faraday showed in 1845 that while some are attracted by a magnet others are repelled. The former he called *paramagnetic* and the latter *diamagnetic* bodies.

The following is a list of these :—

| *Paramagnetic.* | *Diamagnetic.* |
|---|---|
| Iron. | Bismuth. |
| Nickel. | Phosphorus. |
| Cobalt. | Antimony. |
| Aluminium. | Zinc. |
| | Mercury. |
| | Lead. |

| | |
|---|---|
| Manganese. | Silver. |
| Chromium. | Copper. |
| Cerium. | Gold. |
| Titanium. | Water. |
| Platinum. | Alcohol. |
| Many ores and salts of the above metals. | Tellurium. |
| | Selenium. |
| | Sulphur. |
| | Thallium. |
| Oxygen. | Hydrogen. |
| | Air. |

We have theories of magnetism that reduce it to a phenomenon of electricity, though we are ignorant of the real nature of both. If we take a thin bar magnet and break it in two, we find that we have now two shorter magnets, each with its "north" and "south" poles, that is to say, poles of the same kind as the south and north magnetic poles of the earth. If we break each of these again, we get four smaller magnets, and we can repeat the process as often as we like. It is supposed, therefore, that every atom of the bar is a little magnet in itself having its two opposite poles, and that in magnetising the bar we have merely partially turned all these atoms in one direction, that is to say, with their north poles pointing one way and their south poles the other way, as shown in figure 27. The polarity of the bar only shows itself at the ends, where the molecular poles are, so to speak, free.

There are many experiments which support this view. For example, if we heat a magnet red hot it loses its magnetism, perhaps because the heat has disarranged the particles and set the molecular poles in all directions. Again, if

we magnetise a piece of soft iron we can destroy its magnetism by striking it so as to agitate its atoms and throw them out of line. In steel, which is iron with a small admixture of carbon, the atoms are not so free as in soft iron, and hence, while iron easily loses its magnetism, steel

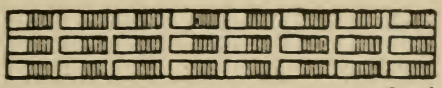



FIG. 27.

retains it, even under a shock, but not under a cherry red-heat. Nevertheless, if we put the atoms of soft iron under a strain by bending it, we shall find it retain its magnetism more like a bit of steel.

It has been found, too, that the atoms show an indisposition to be moved by the magnetising force which is known as *hysteresis*. They have a certain inertia, which can be overcome by a slight shock, as though they had a difficulty of turning in the ranks to take up their new positions. Even if this molecular theory is true, however, it does not help us to explain why a molecule of matter is a tiny magnet. We have only pushed the mystery back to the atom. Something more is wanted, and electricians look for it in the constitution of the atom, and in the luminiferous ether which is believed to surround the atoms of matter, and to propagate not merely the waves of light, but induction from one electrified body to another.

We know in proof of this ethereal action that the space around a magnet is magnetic. Thus, if we lay a horse-shoe magnet on a table and

sprinkle iron filings round it, they will arrange themselves in curving lines between the poles as shown in figure 28. Each filing has become a little magnet, and these set themselves end to end as the molecules in the metal are supposed to do. The "field" about the magnet is replete with these lines, which follow certain curves depending on the arrangement of the poles. In the horse-shoe magnet, as seen, they chiefly issue from one pole and sweep round to the other. They are never broken, and apparently they are lines of stress in the circumambient ether. A pivoted magnet tends to range itself along these lines, and thus the compass guides the sailor on the ocean by keeping itself in the line between the north and south magnetic poles of the earth.

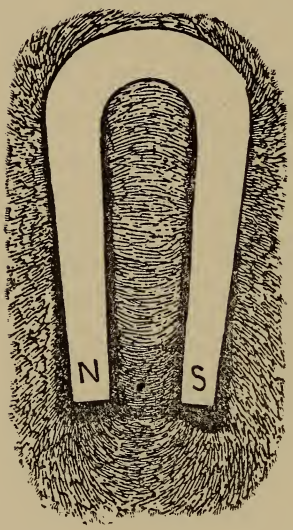


FIG. 28.

Faraday called them *lines of magnetic force*, and said that the stronger the magnet the more of these lines pass through a given space. Along them "magnetic induction" is supposed to be propagated, and a magnet is thus enabled to attract iron or any other magnetic substance. The pole induces an opposite pole to itself in the nearest part of the induced body and a like pole in the remote part. Consequently, as unlike poles at-

tract and like repel, the soft iron is attracted by the inducing pole much as a pithball is attracted by an electric charge.

The resemblances of electricity and magnetism did not escape attention, and the derangement of the compass needle by the lightning flash, formerly so disastrous at sea, pointed to an intimate connection between them, which was ultimately disclosed by Professor Oersted, of Copenhagen, in the year 1820. Oersted was on the outlook for the required clue, and a happy chance is said to have rewarded him. His experiment is shown in figure 29, where a wire conveying a current of

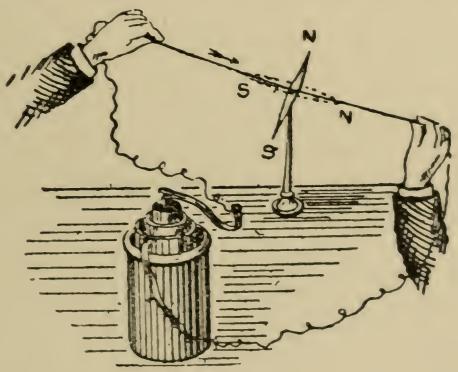



FIG. 29.

electricity flowing in the direction of the arrow is held over a pivoted magnetic needle so that the current flows from south to north. The needle will tend to set itself at right angles to the wire, its north or north-seeking pole moving towards the west. If the direction of the current is reversed, the needle is deflected in the opposite

direction, its north pole moving towards the east. Further, if the wire is held below the needle, in the first place, the north pole will turn towards the east, and if the current be reversed it will move towards the west.

The direction of a current can thus be told with the aid of a compass needle. When the wire is wound many times round the needle on a bobbin, the whole forms what is called a galvanoscope, as shown in figure 30, where *N* is the

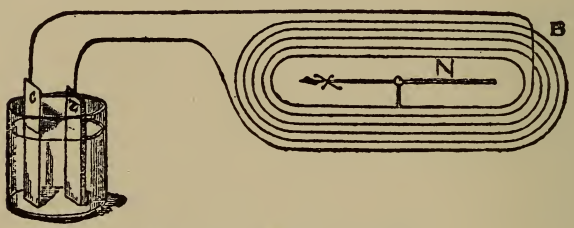



FIG. 30.—The Galvanoscope.

needle and *B* the bobbin. When a proper scale is added to the needle by which its deflections can be accurately read, the instrument becomes a current measurer or galvanometer, for within certain limits the deflection of the needle is proportional to the strength of the current in the wire.

A rule commonly given for remembering the movement of the needle is as follows :—Imagine yourself laid along the wire so that the current flows from your feet to your head ; then if you face the needle you will see its north pole go to the left and its south pole to the right. I find it simpler to recollect that if the current flows from your head to your feet a north pole will move round you from left to right in front. Or, again, if a current flows from north to south, a north

pole will move round it like the sun round the earth.

The influence of the current on the needle implies a magnetic action, and if we dust iron filings around the wire we shall find they cling to it in concentric layers, showing that circular lines of magnetic force enclose it like the water waves caused by a stone dropped into a pond. Figure 31 represents the section of a wire carrying a current, with the iron filings arranged in circles round it. Since a magnetic pole tends to move in the direction of the lines of force, we now see why a north or south pole tends to move *round* a current, and why a compass needle tries to set itself at right angles to a current, as in the original experiment of Oersted. The needle, having two opposite poles, is pulled in opposite directions by the lines, and being pivoted, sets itself tangentically to them. Were it free and flexible, it would curve itself along one of the lines. Did it consist of a single pole, it would revolve round the wire.

FIG. 31.

Action and re-action are equal and opposite, hence if the needle is fixed and the wire free the current will move round the magnet; and if both are free they will circle round each other. Applying the above rule we shall find that when the north pole moves from left to right the current moves from right to left. Ampère of Paris, following Oersted, promptly showed that two parallel wires carrying currents attracted each other when the currents flowed in the same direction, and repelled each other when they flowed in opposite directions. Thus, in figure 32, if *A* and

*B* are the two parallel wires, and *A* is mounted on pivots and free to move in liquid "contacts" of mercury, it will be attracted or repelled by *B* according as the two currents flow in the same or in opposite directions. If the wires cross each other at right angles there is no attraction or repulsion. If they cross at an acute angle, they will tend to become parallel like two compass

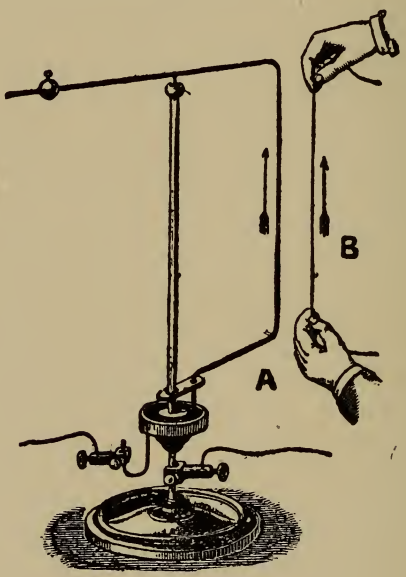



FIG. 32.

needles, when the currents are in one direction, and to open to a right angle and close up the other way when the currents are in opposite directions, always tending to arrange themselves parallel and flowing in the same direction. These

effects arise from the circular lines of force around the wire. When the currents are similar the lines act as unlike magnetic poles and attract, but when the currents are dissimilar the lines act as like magnetic poles and repel each other.

Another important discovery of Ampère is that a circular current behaves like a magnet; and it has been suggested by him that the atoms are magnets because each has a circular current flowing round it. A series of circular currents, such as the spiral *S* in figure 33 gives, when connected to a battery *C Z*, is in fact a skeleton

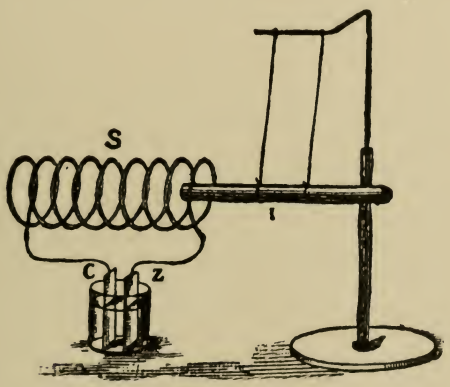



FIG. 33.

*electro-magnet* having its north and south poles at the extremities. If a rod or core of soft iron *I* be suspended by fibres from a support, it will be sucked towards the middle of the coil as into a vortex, by the circular magnetic lines of every spire or turn of the coil. Such a combination is sometimes called a solenoid, and is useful in practice.

When the core gains the interior of the coil it becomes a veritable electromagnet, as found by Arago, having a north pole at one end and a south pole at the other. Figure 34 illustrates a common poker magnetised in the same way, and supporting nails at both ends. The poker has

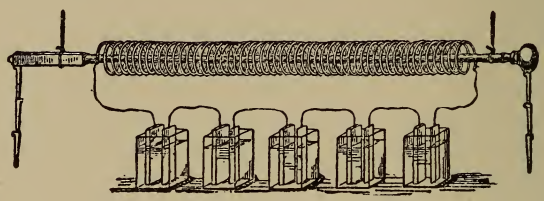


FIG. 34.

become the core of the electromagnet. On reversing the direction of the current through the spiral we reverse the poles of the core, for the poker being of soft or wrought iron, does not retain its magnetism like steel. If we stop the current altogether it ceases to be a magnet, and the nails will drop away from it.

Ampère's experiment in figure 32 has shown us that two currents, more or less parallel, influence each other; but in 1831 Professor Faraday of the Royal Institution, London, also found that when a current is started and stopped in a wire, it induces a momentary and opposite current in a parallel wire. Thus, if a current is *started* in the wire *B* (fig. 32) in direction of the arrow, it will induce or give rise to a momentary current in the wire *A*, flowing in a contrary direction to itself. Again, if the current in *B* be *stopped*, a momentary current is set up in the wire *A* in a direction the same as that of the exciting current

in *B*. While the current in *B* is quietly flowing there is no induced current in *A*; and it is only at the start or the stoppage of the inducing or *primary* current that the induced or *secondary* current is set up. Here again we have the influence of the magnetic field around the wire conveying a current.

This is the principle of the "induction coil" so much employed in medical electricity, and of the "transformer" or "converter" used in electric illumination. It consists essentially, as shown in figure 35, of two coils of wire, one enclosing the other, and both parallel or concentric. The inner

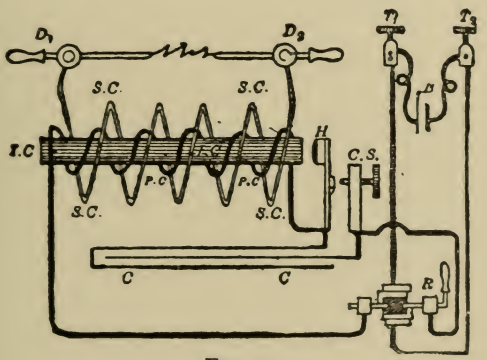



FIG. 35.

or primary coil *P C* is of short thick wire of low resistance, and is traversed by the inducing current of a battery *B*. To increase its inductive effect a core of soft iron *I C* occupies its middle. The outer or secondary coil *S C* is of long thin wire terminating in two discharging points $D_1$ $D_2$. An interruptor or hammer "key" interrupts or "makes and breaks" the circuit of the primary

coil very rapidly, so as to excite a great many induced currents in the secondary coil per second, and produce energetic sparks between the terminals $D_1$ $D_2$. The interruptor is actuated automatically by the magnetism of the iron core *I C*, for the hammer *H* has a soft iron head which is attracted by the core when the latter is magnetised, and being thus drawn away from the contact screw *C S* the circuit of the primary is broken, and the current is stopped. The iron core then ceases to be a magnet, the hammer *H* springs back to the contact screw, and the current again flows in the primary circuit only to be interrupted again as before. In this way the current in the primary coil is rapidly started and stopped many times a second, and this, as we know, induces corresponding currents in the secondary which appear as sparks at the discharging points. The effect of the apparatus is enhanced by interpolating a "condenser" *C C* in the primary circuit. A condenser is a form of Leyden jar, suitable for current electricity, and consists of layers of tinfoil separated from each other by sheets of paraffin paper, mica, or some other convenient insulator, and alternate foils are connected together. The wires joining each set of plates are the poles of the condenser, and when these are connected in the circuit of a current the condenser is charged. It can be discharged by joining its two poles with a wire, and letting the two opposite electricities on its plates rush together. Now, the sudden discharge of the condenser *C C* through the primary coil *P C* enhances the inductive effect of the current. The battery *B*, here shown by the conventional symbol "▮|" where the thick dash is the negative and the thin

dash the positive pole, is connected between the terminals $T_1$ $T_2$, and a *commutator* or pole-changer $R$, turned with a handle, permits the direction of the current to be reversed at will.

Figure 36 represents the exterior of an ordinary induction coil of the Ruhmkorff pattern,

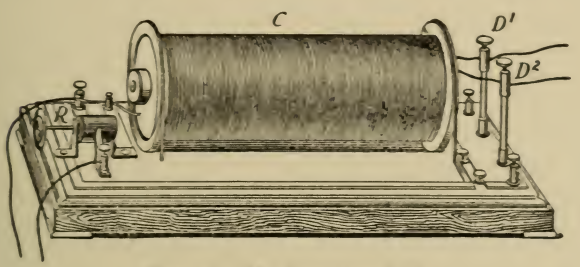



FIG. 36.—The Induction Coil.

with its two coils, one over the other $C$, its commutator $R$, and its sparkling points $D_1$ $D_2$, the whole being mounted on a mahogany base, which holds the condenser.

The intermittent, or rather alternating, currents from the secondary coil are often applied to the body in certain nervous disorders. When sent through glass tubes filled with rarefied gases, sometimes called "Geissler tubes," they elicit glows of many colours, vieing in beauty with the fleeting tints of the aurora polaris, which, indeed, is probably a similar effect of electrical discharges in the atmosphere.

The action of the induction is reversible. We can not only send a current of low "pressure" from a generator of weak electromotive force through the primary coil, and thus excite a current of high pressure in the secondary coil, but

we can send a current of high pressure through the secondary coil and provoke a current of low pressure in the primary coil. The transformer or converter, a modified induction coil used in distributing electricity to electric lamps and motors,

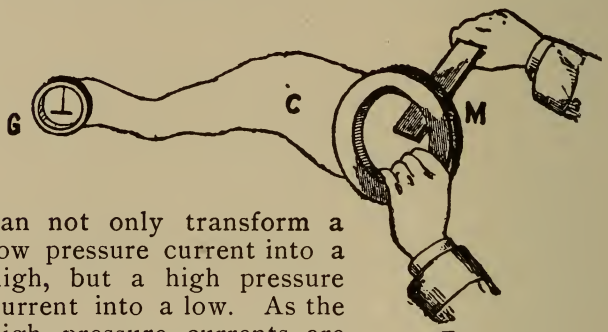



Fig. 37.

can not only transform a low pressure current into a high, but a high pressure current into a low. As the high pressure currents are best able to overcome the resistance of the wire conveying them, it is customary to transmit high pressure currents from the generator to the distant place where they are wanted by means of small wires, and there transform them into currents of the pressure required to light the lamps or drive the motors.

We come now to another consequence of Oersted's great discovery, which is doubtless the most important of all, namely, the generation of electricity from magnetism, or, as it is usually called, magneto-electric induction. In the year 1831 the illustrious Michael Faraday further succeeded in demonstrating that when a magnet *M* is thrust into a hollow coil of wire *C*, as shown in figure 37, a current of electricity is set up in the coil whilst the motion lasts. When the magnet is withdrawn again another current is induced in

the reverse direction to the first. If the coil be closed through a small galvanometer *G* the movements of the needle to one side or the other will indicate these temporary currents. It follows from the principle of action and reaction that if the magnet is kept still and the coil thrust over it similar currents will be induced in the coil. All that is necessary is for the wires to cut the lines of magnetic force around the magnet, or, in other words, the lines of force in a magnetic field. We have seen already that a wire conveying a current can move a magnetic pole, and we are therefore prepared to find that a magnetic pole moved near a wire can excite a current in it.

Figure 38 illustrates the conditions of this remarkable effect, where *N* and *S* are two magnetic poles with lines of force between them, and *W* is a wire crossing these lines at right angles, which is the best position. If, now, this wire be moved so as to sink bodily through the paper away from the reader, an electric current flowing in the direction of the arrow will be induced in it. If, on the contrary, the wire be moved across the lines of force towards the reader, the induced current will flow oppositely to the arrow. Moreover, if the poles of the magnet *N* and *S* exchange places, the directions of the induced currents will also be reversed. This is the fundamental principle of the well-known dynamo-electric machine, popularly called a dynamo.

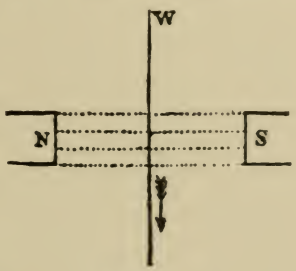


FIG. 38.

Again, if we send a current from some external source through the wire *W* in the direction of the arrow, the wire will move *of itself* across the lines of force away from the reader, that is to say, in the direction it would need to be moved in order to excite such a current; and if, on the other hand, the current be sent through it in the reverse direction to the arrow, it will move towards the reader. This is the principle of the equally well-known electric motor. Figure 39 shows a simple method of remembering these directions.

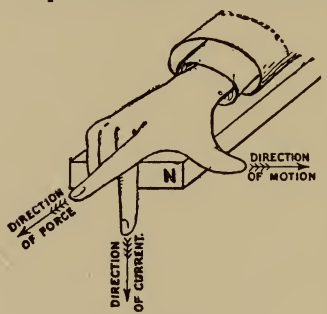



FIG. 39.

Let the right hand rest on the north pole of a magnet and the forefinger be extended in the direction of the lines of force, then the outstretched thumb will indicate the direction in which the wire or conductor moves and the bent middle finger the direction of the current. These three digits, as will be noticed, are all at right angles to each other, and this relation is the best for inducing the strongest current in a dynamo or the most energetic movement of the conductor in an electric motor.

Of course in a dynamo-electric generator the stronger the magnetic field, the less the resistance of the conductor, and the faster it is moved across the lines of force, that is to say, the more lines it cuts in a second the stronger is the current produced. Similarly in an electric motor, the stronger the current

and magnetic field the faster will the conductor move.

The most convenient motion to give the conductor in practice is one of rotation, and hence the dynamo usually consists of a coil or series of coils of insulated wire termed the "armature," which is mounted on a spindle and rapidly rotated in a strong magnetic field between the poles of powerful magnets. Currents are generated in the coils, now in one direction then in another, as they revolve or cross different parts of the field; and, by means of a device termed a commutator, these currents can be collected or sifted at will, and led away by wires to an electric lamp, an accumulator, or an electric motor, as desired. The character of the electricity is precisely the same as that generated in the voltaic battery.

The commutator may only collect the currents as they are generated, and supply what is called an alternating current, that is to say, a current which alternates or changes its direction several hundred times a second, or it may sift the currents as they are produced and supply what is termed a continuous current, that is, a current always in the same direction, like that of a voltaic battery. Some machines are made to supply alternating currents, others continuous currents. Either class of current will do for electric lamps, but only continuous currents are used for electo-plating, or, in general, for electric motors.

In the "magneto-electric" machine the *field magnets* are simply steel bars permanently magnetised, but in the ordinary dynamo the field magnets are electro-magnets excited to a high

pitch by means of the current generated in the moving conductor or armature. In the "series-wound" machine the whole of the current generated in the armature also goes through the coils of the field magnets. Such a machine is sketched in figure 40, where *A* is the armature, consisting of an iron core surrounded by coils of wire and rotating in the field of a powerful electro-magnet *NS* in the direction of the arrows. For the sake of simplicity only twelve coils are

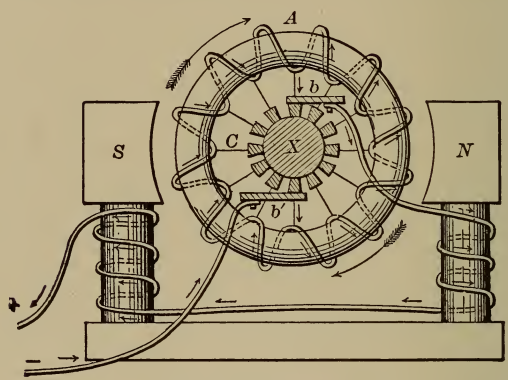



FIG. 40.—A Dynamo.

represented. They are all in circuit one with another, and a wire connects the ends of each coil to corresponding metal bars on the commutator *c*. These bars are insulated from each other on the spindle *X* of the armature. Now, as each coil passes through the magnetic field in turn, a current is excited in it. Each coil therefore resembles an individual cell of a voltaic battery, connected in series. The current is drawn off from the ring by two copper "brushes" *b*, *b'*,

which rub upon the bars of the commutator at opposite ends of a diameter, as shown. One brush is the positive pole of the dynamo, the other is the negative, and the current will flow through any wire or external circuit which may be connected with these, whether electric lamps, motors, accumulators, electro-plating baths, or other device. The small arrows show the movements of the current throughout the machine, and the terminals are marked (+) positive and (−) negative.

It will be observed that the current excited in the armature also flows through the coils of the electro-magnets, and thus keeps up their strength. When the machine is first started the current is feeble, because the field of the magnets in which the armature revolves is merely that due to the dregs or "residual magnetism" left in the soft iron cores of the magnet since the last time the machine was used. But this feeble current exalts the strength of the field-magnets, producing a stronger field, which in turn excites a still stronger current in the armature, and this process of give and take goes on until the full strength or "saturation" of the magnets is attained.

Such is the "series" dynamo, of which the well-known Gramme machine is a type. Figure 41 illustrates this machine as it is actually made, *A* being the armature revolving between the poles *N S* of the field-magnets *M M*, *M' M'*, on a spindle which is driven by means of a belt on the pulley *P* from a separate engine. The brushes *b b'* of the commutator *C* collect the current, which in this case is continuous, or constant in its direction.

The current of the series machine varies with the resistance of the external or working circuit, because that is included in the circuit of the field magnets and the armature. Thus, if we vary the number of electric lamps fed by the machine, we shall vary the current it is capable of yielding. With arc lamps in series, by adding to the number in circuit we increase the resistance of the outer

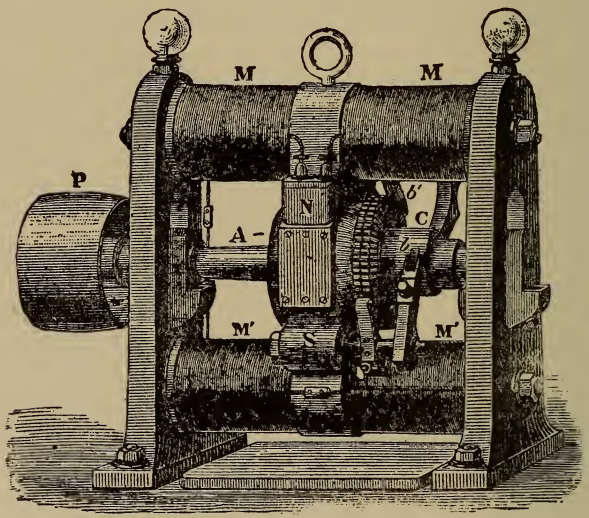



FIG. 41.

circuit, and therefore diminish the strength of the current yielded by the machine, because the current, weakened by the increase of resistance, fails to excite the field magnets as strongly as before. On the other hand, with glow lamps arranged in parallel, the reverse is the case, and putting more lamps in circuit increases the power

of the machine, by diminishing the resistance of the outer circuit in providing more cross-cuts for the current. This, of course, is a drawback to the series machine in places where the number of lamps to be lighted varies from time to time. In the "shunt-wound" machine the field magnets are excited by diverting a small portion of the main current from the armature through them, by means of a "shunt" or loop circuit. Thus in figure 42 where *C* is the commutator and *b b'* the brushes, *M* is a shunt circuit through the magnets, and *E* is the external or working circuit of the machine.

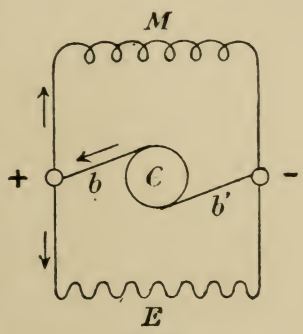


FIG. 42.

The small arrows indicate the directions of the currents. With this arrangement the addition of more glow lamps to the external circuit *E* *diminishes* the current, because the portion of it which flows through the by-path *M*, and excites the magnets, is less now that the alternative route for the current through *E* is of lower resistance than before. When fewer glow lamps are in the external circuit *E*, and its resistance therefore higher, the current in the shunt circuit *M* is greater than before, the magnets become stronger, and the electromotive force of the armature is increased. The Edison machine is of this type, and is illustrated in figure 43, where *M M'* are the field magnets with their poles *N S*, between which the armature *A* is revolved by means of the belt *B*, and a pulley seen behind.

The leading wires *W W* convey the current from the brushes of the commutator to the external

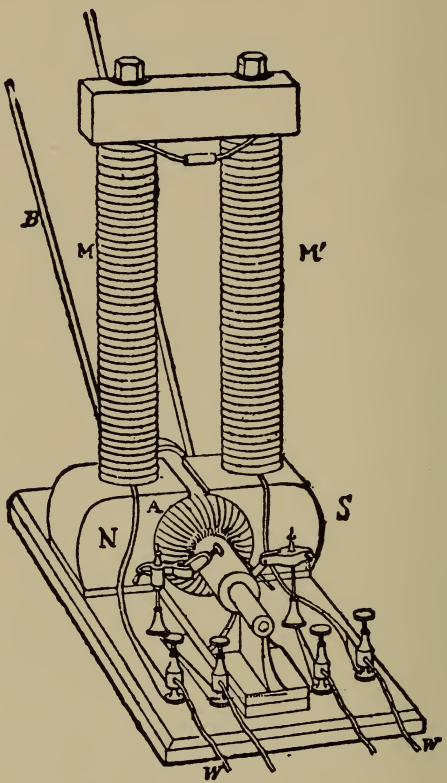



FIG. 43.

circuit. In this machine the conductors of the armature are not coils of wire, but separate bars of copper.

In shunt machines the variation of current due

to a varying number of lamps in use occasions a rise and fall in the brightness of the lamps which is undesirable, and hence a third class of dynamo has been devised, which combines the principles of both the series and shunt machines. This is the "compound-wound" machine, in which the magnets are wound partly in shunt and partly in series with the armature, in such a manner that the strength of the field-magnets and the electromotive force of the current do not vary much, whatever be the number of lamps in circuit. In alternate current machines the electromotive force keeps constant, as the field-magnets are excited by a separate machine, giving a continuous current.

We have already seen that the action of the dynamo is reversible, and that just as a wire moved across a magnetic field supplies an electric current, so a wire at rest, but conducting a current across a magnetic field, will move. The electric motor is therefore essentially a dynamo, which on being traversed by an electric current from an external source puts itself in motion. Thus, if a current be sent through the armature of the Gramme machine, shown in figure 41, the armature will revolve, and the spindle, by means of a belt on the pulley *P*, can communicate its energy to another machine.

Hence the electric motor can be employed to work lathes, hoists, lifts, drive the screws of boats or the wheels of carriages, and for many other purposes. There are numerous types of electric motor as of the dynamo in use, but they are all modifications of the simple continuous or alternating current dynamo.

Obviously, since mechanical power can be

converted into electricity by the dynamo, and reconverted into mechanical power by the motor, it is sufficient to connect a dynamo and motor together by insulated wire in order to transmit mechanical power, whether it be derived from wind, water, or fuel, to any reasonable distance.

## CHAPTER V.

### ELECTROLYSIS.

HAVING seen how electricity can be generated and stored in considerable quantity, let us now turn to its practical uses. Of these by far the most important are based on its property of developing light and heat as in the electric spark, chemical action as in the voltameter, and magnetism as in the electromagnet.

The words "current," "pressure," and so on point to a certain analogy between electricity and water, which helps the imagination to figure what can neither be seen nor handled, though it must not be traced too far. Water, for example, runs by the force of gravity from a place of higher to a place of lower level. The pressure of the stream is greater the more the difference of level or "head of water." The strength of the current or quantity of water flowing per second is greater the higher the pressure, and the less the resistance of its channel. The power of the water or its rate of doing mechanical work is greater the higher the pressure and the stronger the current.

So, too, electricity flows by the electromotive force from a place of higher to a place of lower

electric level or potential. The electric pressure is greater the more the difference of potential or electromotive force. The strength of the electric current or quantity of electricity flowing per second is greater the higher the pressure or electromotive force and the less the resistance of the circuit. The power of the electricity or its rate of doing work is greater the higher the electromotive force and the stronger the current.

It follows that a small quantity of water or electricity at a high pressure will give us the same amount of energy as a large quantity at a low pressure, and our choice of one or the other will depend on the purpose we have in view. As a rule, however, a large current at a comparatively low or moderate pressure is found the more convenient in practice.

The electricity of friction belongs to the former category, and the electricity of chemistry, heat, and magnetism to the latter. The spark of a frictional or influence machine can be compared to a highland cataract of lofty height but small volume, which is more picturesque than useful, and the current from a voltaic battery, a thermopile, or a dynamo to a lowland river which can be dammed to turn a mill. It is the difference between a skittish gelding and a tame cart-horse.

Not the spark from an induction coil or Leyden jar, but a strong and steady current at a low pressure, is adapted for electrolysis or electro-deposition, and hence the voltaic battery or a special form of dynamo is usually employed in this work. A flash of lightning is the very symbol of terrific power, and yet, according to the illustrious Faraday, it contains a smaller amount of electricity

than the feeble current required to decompose a single drop of rain.

In our simile of the mill dam and the battery or dynamo, the dam corresponds to the positive pole and the river or sea below the mill to the negative pole. The mill-race will stand for the wire joining the poles, that is to say, the external circuit, and the mill-wheel for the work to be done in the circuit, whether it be a chemical for decomposition, a telegraph instrument, an electric lamp, or any other appliance. As the current in the race depends on the "head of water," or difference of level between the dam and the sea as well as on the resistance of the channel, so the current in the circuit depends on the "electromotive force," or difference of potential between the positive and negative poles, as well as on the resistance of the circuit. The relation between these is expressed by the well-known law of Ohm, which runs: *A current of electricity is directly proportional to the electromotive force and inversely proportional to the resistance of the circuit.*

In practice electricity is measured by various units or standards named after celebrated electricians. Thus the unit of quantity is the *coulomb*, the unit of current or quantity flowing per second is the *ampère*, the unit of electromotive force is the *volt*, and the unit of resistance is the *ohm*.

The quantity of water or any other "electrolyte" decomposed by electricity is proportional to the strength of the current. One ampère decomposes .00009324 gramme of water per second, liberating .000010384 gramme of hydrogen and .00008286 gramme of oxygen.

The quantity in grammes of any other chemical element or *ion* which is liberated from an elec-

trolyte or body capable of electro-chemical decomposition in a second by a current of one ampère is given by what is called the electro-chemical equivalent of the ion. This is found by multiplying its ordinary chemical equivalent or combining weight by .00001038$_4$, which is the electro-chemical equivalent of hydrogen. Thus the weight of metal deposited from a solution of any of its salts by a current of so many ampères in so many seconds is equal to the number of ampères multiplied by the number of seconds, and by the electro-chemical equivalent of the metal.

The deposition of a metal from a solution of its salt is very easily shown in the case of copper. In fact, we have already seen that in the Daniell cell the current decomposes a solution of sulphate of copper and deposits the pure metal on the copper plate. If we simply make a solution of blue vitriol in a glass beaker and dip the wires from a voltaic cell into it, we shall find the wire from the negative pole become freshly coated with particles of new copper. The sulphate has been broken up, and the liberated metal, being positive, gathers on the negative electrode. Moreover, if we examine the positive electrode we shall find it slightly eaten away, because the sulphuric acid set free from the sulphate has combined with the particles of that wire to make new sulphate. Thus the copper is deposited on one electrode, namely, the cathode, by which the current leaves the bath, and at the expense of the other electrode, that is to say, the anode, by which the current enters the bath.

The fact that the weight of metal deposited in this way from its salts is proportional to the current, has been utilised for measuring the

strength of currents with a fine degree of accuracy. If, for example, the tubes of the voltameter described on page 38 were graduated, the volume of gas evolved would be a measure of the current. Usually, however, it is the weight of silver or copper deposited from their salts in a certain time which gives the current in ampères.

Electro-plating is the principal application of this chemical process. In 1805 Brugnatelli took a silver medal and coated it with gold by making it the cathode in a solution of a salt of gold, and using a plate of gold for the anode. The shops of our jewellers are now bright with teapots, salt cellars, spoons, and other articles of the table made of inferior metals, but beautified and preserved from rust in this way.

Figure 44 illustrates an electro-plating bath

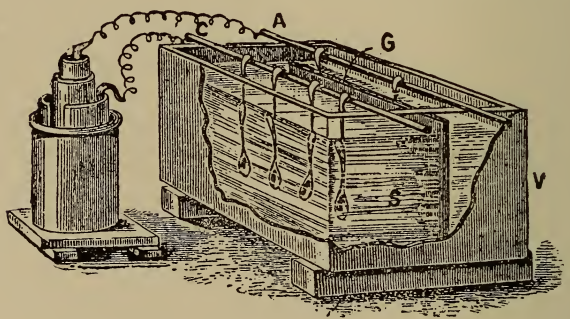



Fig. 44.

in which a number of spoons are being plated. A portion of the vat *V* is cut away to show the interior, which contains a solution *S* of the double cyanide of gold and potassium when gold is to be

laid, and the double cyanide of silver and potassium when silver is to be deposited. The electrodes are hung from metal rods, the anode *A* being a plate of gold or silver *G*, as the case may be, and the cathode *C* the spoons in question. When the current of the battery or dynamo passes through the bath from the anode to the cathode, gold or silver is deposited on the spoons, and the bath recuperates its strength by consuming the gold or silver plate.

Enormous quantities of copper are now deposited in a similar way, sulphate of copper being the solution and a copper plate the anode. Large articles of iron, such as the parts of ordnance, are sometimes copper-plated to preserve them from the action of the atmosphere. Seamless copper pipes for conveying steam, and wires of pure copper for conducting electricity, are also deposited, and it is not unlikely that the kettle of the future will be made by electrolysis.

Nickel-plating is another extensive branch of the industry, the white nickel forming a cloak for metals more subject to corrosion. Nickel is found to deposit best from a solution of the double sulphate of nickel and ammonia. Aluminium, however, has not yet been successfully deposited by electricity.

In 1836 De la Rue observed that copper laid in this manner on another surface took on its under side an accurate impression of that surface, even to the scratches on it, and three years later Jacobi, of St. Petersburg, and Jordan, of London, applied the method to making copies or replicas of medals and woodcuts. Even non-metallic surfaces could be reproduced in copper by taking a cast of them in wax and lining the mould with

fine plumbago, which, being a conductor, served as a cathode to receive the layer of metal. It is by the process of electrotyping or galvano-plastics that the copper faces for printing woodcuts are prepared, and copies made of seals or medals.

Natural objects, such as flowers, ferns, leaves, feathers, insects, and lizards, can be prettily coated with bronze or copper, not to speak of gold and silver, by a similar process. They are too delicate to be coated with black lead in order to receive the skin of metal, but they can be dipped in solutions, leaving a film which can be reduced to gold or silver. For instance, they may be soaked in an alcoholic solution of nitrate of silver, made by shaking 2 parts of the crystals in 100 parts of alcohol in a stoppered bottle. When dry, the object should be suspended under a glass shade and exposed to a stream of sulphuretted hydrogen gas; or it may be immersed in a solution of 1 part of phosphorus in 15 parts of bisulphide of carbon, 1 part of bees-wax, 1 part of spirits of turpentine, 1 part of asphaltum, and $\frac{1}{8}$ part of caoutchouc dissolved in bisulphide of carbon. This leaves a superficial film which is metallised by dipping in a solution of 20 grains of nitrate of silver to a pint of water. On this metallic film a thicker layer of gold and silver in different shades can be deposited by the current, and the silver surface may also be "oxidised" by washing it in a weak solution of platinum chloride.

Electrolysis is also used to some extent in reducing metals from their ores, in bleaching fibre, in manufacturing hydrogen and oxygen from water, and in the chemical treatment of sewage.

## CHAPTER VI.

### THE TELEGRAPH AND TELEPHONE.

LIKE the "philosopher's stone," the "elixir of youth," and "perpetual motion," the telegraph was long a dream of the imagination. In the sixteenth century, if not before, it was believed that two magnetic needles could be made sympathetic, so that when one was moved the other would likewise move, however far apart they were, and thus enable two distant friends to communicate their minds to one another.

The idea was prophetic, although the means of giving effect to it were mistaken. It became practicable, however, when Oersted discovered that a magnetic needle could be swung to one side or the other by an electric current passing near it.

The illustrious Laplace was the first to suggest a telegraph on this principle. A wire connecting the two poles of a battery is traversed, as we know, by an electric current, which makes the round of the circuit, and only flows when that circuit is complete. However long the wire may be, however far it may run between the poles, the current will follow all its windings, and finish its course from pole to pole of the battery. You may lead the wire across the ocean and back, or round the world if you will, and the current will travel through it.

The moment you break the wire or circuit, however, the current will stop. By its electromotive force it can overcome the resistance of the many miles of conductor; but unless it be

unusually strong it cannot leap across even a minute gap of air, which is one of the best insulators.

If, then, we have a simple device easily manipulated by which we can interrupt the circuit of the battery, in accordance with a given code, we shall be able to send a series of currents through the wire and make sensible signals wherever we choose. These signs can be produced by the deviation of a magnetic needle, as Laplace pointed out, or by causing an electro-magnet to attract soft iron, or by chemical decomposition, or any other sensible effect of the current.

Ampère developed the idea of Laplace into a definite plan, and in 1830 or thereabout Ritchie, in London, and Baron Schilling, in St. Petersburg, exhibited experimental models. In 1833 and afterwards Professors Gauss and Weber installed a private telegraph between the observatory and the physical cabinet of the University of Göttingen. Moreover, in 1836 William Fothergill Cooke, a retired surgeon of the Madras army, attending lectures on anatomy at the University of Heidelberg, saw an experimental telegraph of Professor Möncke, which turned all his thoughts to the subject. On returning to London he made the acquaintance of Professor Wheatstone, of King's College, who was also experimenting in this direction, and in 1836 they took out a patent for a needle telegraph. It was tried successfully between the Euston terminus and the Camden Town station of the London and North-Western Railway on the evening of July 25th, 1837, in presence of Mr. Robert Stephenson, and other eminent engineers. Wheatstone, sitting in a small room near the booking-office at

Euston, sent the first message to Cooke at Camden Town, who at once replied. "Never," said Wheatstone, "did I feel such a tumultuous sensation before, as when, all alone in the still room, I heard the needles click, and as I spelled the words I felt all the magnitude of the invention pronounced to be practicable without cavil or dispute."

The importance of the telegraph in working railways was manifest, and yet the directors of the company were so purblind as to order the removal of the apparatus, and it was not until two years later that the Great Western Railway Company adopted it on their line from Paddington to West Drayton, and subsequently to Slough. This was the first telegraph for public use, not merely in England, but the world. The charge for a message was only a shilling, nevertheless few persons availed themselves of the new invention, and it was not until its fame was spread abroad by the clever capture of a murderer named Tawell that it began to prosper. Tawell had killed a woman at Slough, and on leaving his victim took the train for Paddington. The police, apprised of the murder, telegraphed a description of him to London. The original "five needle instrument," now in the museum of the Post Office, had a dial in the shape of a diamond, on which were marked the letters of the alphabet, and each letter of a word was pointed out by the movements of a pair of needles. The dial had no letter "q," and as the man was described as a quaker the word was sent "kwaker." When the train arrived at Paddington he was shadowed by detectives, and to his utter astonishment was quietly arrested in a tavern near Cannon Street.

In Cooke and Wheatstone's early telegraph the wire travelled the whole round of the circuit, but it was soon found that a "return" wire in the circuit was unnecessary, since the earth itself could take the place of it. One wire from the sending station to the receiving station was sufficient, provided the apparatus at each end were properly connected to the ground. This use of the earth not only saved the expense of a return wire, but diminished the resistance of the circuit, because the earth offered practically no resistance.

Figure 45 is a diagram of the connections in a

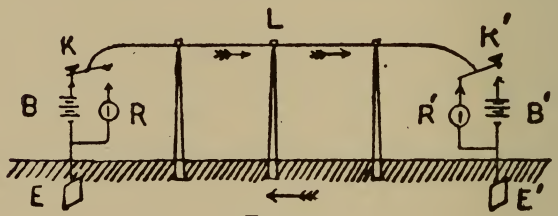



FIG. 45.

simple telegraph circuit. At each of the stations there is a battery $B\,B'$, an interruptor or sending key $K\,K'$ to make and break the continuity of the circuit, a receiving instrument $R\,R'$ to indicate the signal currents by their sensible effects, and connections with ground or "earth plates" $E\,E'$ to engage the earth as a return wire. These are usually copper plates buried in the moist subsoil or the water pipes of a city. The line wire is commonly of iron supported on poles, but insulated from them by earthenware "cups" or *insulators*.

At the station on the left the key is in the act

of *sending* a message, and at the post on the right it is conformably in the position for receiving the message. The key is so constructed that when it is at rest it puts the line in connection with the earth through the *receiving instrument* and the earth plate.

The key $K$ consists essentially of a spring-lever, with two platinum contacts, so placed that when the lever is pressed down by the hand of the telegraphist it breaks contact with the receiver $R$, and puts the line-wire $L$ in connection with the earth $E$ through the battery $B$, as shown on the left. A current then flows into the line and traverses the receiver $R'$ at the distant station, returning or seeming to return to the sending battery by way of the earth plate $E'$ on the right and the intermediate ground.

The duration of the current is at the will of the operator who works the sending-key, and it is plain that signals can be made by currents of various lengths. In the "Morse code" of signals, which is now universal, only two lengths of current are employed—namely, a short, momentary pulse, produced by instant contact of the key, and a jet given by a contact about three times longer. These two signals are called "dot" and "dash," and the code is merely a suitable combination of them to signify the several letters of the alphabet. Thus *e*, the commonest letter in English, is telegraphed by a single "dot," and the letter *t* by a single "dash," while the letter *a* is indicated by a "dot" followed after a brief interval or "space" by a dash.

Obviously, if two *kinds* of current are used, that is to say, if the poles of the battery are reversed by the sending-key, and the direction

of the current is consequently reversed in the circuit, there is no need to alter the length of the signal currents, because a momentary current sent in one direction will stand for a "dot" and in the other direction for a "dash." As a matter of fact, the code is used in both ways, according to the nature of the line and receiving instrument. On submarine cables and with needle and "mirror" instruments, the signals are made by reversing currents of equal duration, but on land lines worked by "Morse" instruments and "sounders," they are produced by short and long currents.

The Morse code is also used in the army for signalling by waving flags or flashing lights, and may also be serviceable in private life. Telegraph clerks have been known to "speak" with each other in company by winking the right and left eye, or tapping with their teaspoon on a cup and saucer. Any two distinct signs, however made, can be employed as a telegraph by means of the Morse code, which runs as shown in figure 46.

The receiving instruments $R\,R^1$ may consist of a magnetic needle pivotted on its centre and surrounded by a coil of wire, through which the current passes and deflects the needle to one side or the other, according to the direction in which it flows. Such was the pioneer instrument of Cooke and Wheatstone, which is still employed in England in a simplified form as the "single" and "double" needle-instrument on some of the local lines and in railway telegraphs. The signals are made by sending momentary currents in opposite directions by a "double current" key, which (unlike the key $K$ in figure 45) reverses the poles

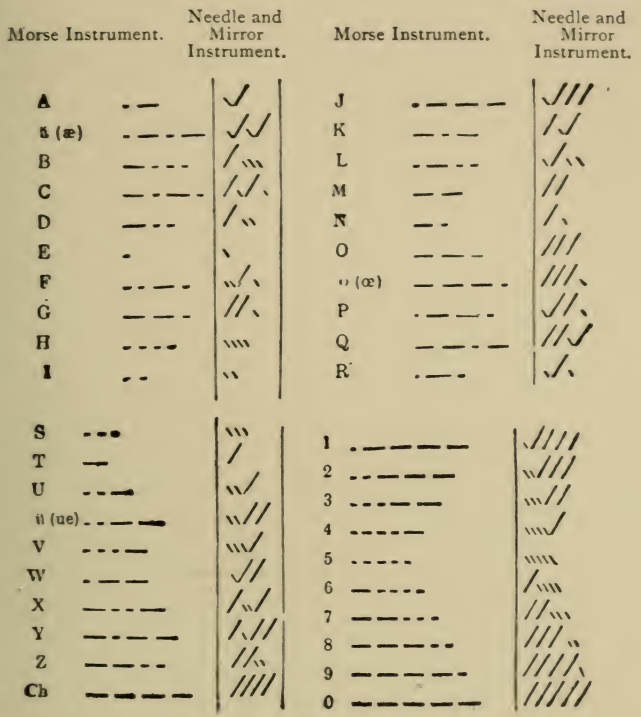



FIG. 46.—Morse Signal Alphabet.

of the battery, in putting the line to one or the other, and thus making the "dot" signal with the "positive" and the "dash" signal with the negative pole. It follows that if the "dot" is indicated by a throw of the needle to the right side, a "dash" will be given by a throw to the left.

Most of the telegraph instruments for land lines are based on the principle of the electro-

magnet. We have already seen (page 59) how Ampère found that a spiral of wire with a current flowing in it behaved like a magnet and was able to suck a piece of soft iron into it. If the iron is allowed to remain there as a core, the combination of coil and core becomes an electromagnet, that is to say, a magnet which is only a magnet so long as the current passes. Figure 47 represents a simple "horse-shoe" electromagnet as invented by Sturgeon. A U-shaped core of soft iron is wound with insulated wire *W*, and when a current is sent through the wire, the core is found to become magnetic with a "north" pole in one end and a "south" pole in the other. These poles are therefore able to attract a separate piece of soft iron or armature *A*. When the current is stopped, however, the core ceases to be a magnet and the armature drops away. In practice the electromagnet usually takes the form shown in figure 48, where the poles are two bobbins or solenoids of wire *S* having straight cores of iron which are united by an iron bar *B*, and *A* is the armature.

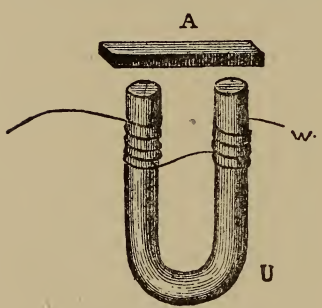



FIG. 47.
A Simple Electro Magnet.

Such an electromagnet is a more powerful device than a swinging needle, and better able to actuate a mechanism. It became the foundation of the recording instrument of Samuel Morse, the father of the telegraph in America. The Morse,

or, rather, Morse and Vail instrument, actually marks the signals in "dots" and "dashes" on a ribbon of moving paper. Figure 49 represents the Morse instrument, in which an electromagnet *M* attracts an iron armature *A* when a current passes through its bobbins, and by means of a lever *L* connected with the armature raises the edge of a small disc out of an ink-pot *I* against the surface of a travelling slip of paper *P*, and marks a dot or dash upon it as the case may be. The rest of the apparatus consists of details and accessories for its action and adjustment, together with the sending-key *K*, which is used in asking for repetitions of the words, if necessary.

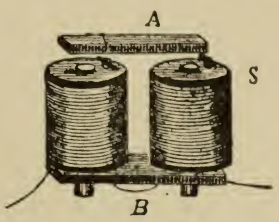


FIG. 48.—Electro Magnet.

A permanent record of the message is of

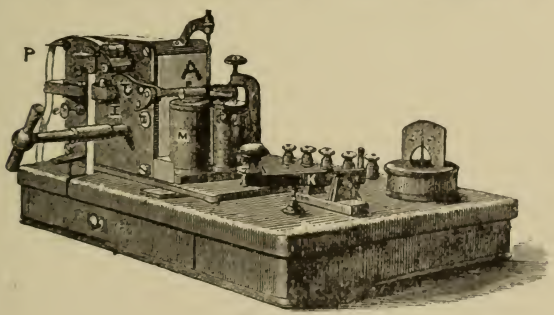


FIG. 49.

course convenient, nevertheless the operators prefer to "read" the signals by the ear, rather than the eye, and, to the annoyance of Morse,

would listen to the click of the marking disc rather than decipher the marks on the paper. Consequently Alfred Vail, the collaborator of Morse, who really invented the Morse code, produced a modification of the recording instrument working solely for the ear. The "sounder," as it is called, has largely driven the "printer" from the field. This neat little instrument is shown in figure 50, where *M* is the electromagnet, and *A* is the armature which chatters up and

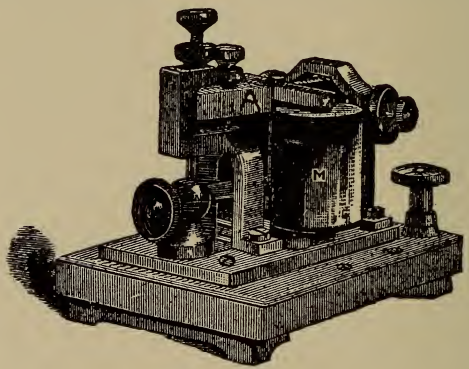


FIG. 50.

down between two metal stops, as the current is made and broken by the sending-key, and the operator listening to the sounds interprets the message letter by letter and word by word.

The motion of the armature in both of these instruments takes a sensible time, but Alexander Bain, of Thurso, by trade a watchmaker, and by nature a genius, invented a chemical telegraph which was capable of a prodigious activity. The instrument of Bain resembled the Morse in marking the signals on a tape of moving paper, but

this was done by electrolysis or electro-chemical decomposition. The paper was soaked in a solution of iodide of potassium in starch and water, and the signal currents were passed through it by a marking stylus or pencil of iron. The electricity decomposed the solution in its passage and left a blue stain on the paper, which corresponded to the dot and dash of the Morse apparatus. The Bain telegraph can record over 1000 words a minute as against 40 to 50 by the Morse or sounder, nevertheless it has fallen into disuse, perhaps because the solution was troublesome.

It is stated that a certain blind operator could read the signals by the smell of the chemical action; and we can well believe it. In fact, the telegraph appeals to every sense, for a deaf clerk can feel the movements of a sounder, and the signals of the current can be told without any instrument by the mere taste of the wires inserted in the mouth.

A skilful telegraphist can transmit twenty-five words a minute with the single-current key, and nearly twice as many by the double-current key, and if we remember that an average English word requires fifteen separate signals, the number will seem remarkable; but by means of Wheatstone's automatic sender 150 words or more can be sent in a minute.

Among telegraphs designed to print the message in Roman type, that of Professor David Edward Hughes is doubtless the fittest, since it is now in general use on the Continent, and conveys our Continental news. In this apparatus the electromagnet, on attracting its armature, presses the paper against a revolving type wheel and receives the print of a type, so that the mes-

sage can be read by a novice. To this effect the type wheel at the receiving station has to keep in perfect time as it revolves, so that the right letter shall be above the paper when the current passes. Small varieties of the type-printer are employed for the distribution of news and prices in most of the large towns, being located in hotels, restaurants, saloons, and other public places, and reporting prices of stocks and bonds, horse races, and sporting and general news. The "duplex system," whereby two messages, one in either direction, can be sent over one wire simultaneously without interfering, and the quadruplex system, whereby four messages, two in either direction, are also sent at once, have come into use where the traffic over the lines is very great. Both of these systems and their modifications depend on an ingenious arrangement of the apparatus at each end of the line, by which the signal currents sent out from one station do not influence the receivers there, but leave them free to indicate the currents from the distant station. When the Wheatstone Automatic Sender is employed with these systems about 500 words per minute can be sent through the line. Press news is generally sent by night, and it is on record, that during a great debate in Parliament, as many as half a million words poured out of the Central Telegraph Station at St. Martin's-le-Grand in a single night to all parts of the country.

Errors occur now and then through bad penmanship or the similarity of certain signals, and amusing telegrams have been sent out, as when the nomination of Mr. Brand for the Speakership of the Commons took the form of "Proposed to brand Speaker"; and an excursion party assured

their friends at home of their security by the message, "Arrived all tight."

Telegraphs, in the literal sense of the word, which actually write the message as with a pen, and make a copy or facsimile of the original, have been invented from time to time. Such are the "telegraphic pen" of Mr. E. A. Cowper, and the "telautographs" of Mr. J. H. Robertson and Mr. Elisha Gray. The first two are based on a method of varying the strength of the current in accordance with the curves of the handwriting, and making the varied current actuate by means of magnetism a writing pen or stylus at the distant station. The instrument of Gray, which is the most successful, works by intermittent currents or electrical impulses, that excite electro-magnets and move the stylus at the far end of the line. They are too complicated for description here, and are not of much practical importance.

Telegraphs for transmitting sketches and drawings have also been devised by D'Ablincourt and others, but they have not come into general use. Of late another step forward has been taken by Mr. Amstutz, who has invented an apparatus for transmitting photographic pictures to a distance by means of electricity. The system may be described as a combination of the photograph and telegraph. An ordinary negative picture is taken, and then impressed on a gelatine plate sensitised with bichromate of potash. The parts of the gelatine in light become insoluble, while the parts in shade can be washed away by water. In this way a relief or engraving of the picture is obtained on the gelatine, and a cross section through the plate would, if looked at edgeways,

appear serrated, or up and down, like a section of country or the trace of the stylus in the record of a phonograph. The gelatine plate thus carved by the action of light and water is wrapped round a revolving drum or barrel, and a spring stylus or point is caused to pass over it as the barrel revolves, after the manner of a phonographic cylinder. In doing so the stylus rises and falls over the projections in the plate and works a lever against a set of telegraph keys, which open electric contacts and break the connections of an electric battery which is joined between the keys and the earth. There are four keys, and when they are untouched the current splits up through four by-paths or bobbins of wire before it enters the line wire and passes to the distant station. When any of the keys are touched, however, the corresponding by-path or bobbin is cut out of circuit. The suppression of a by-path or channel for the current has the effect of adding to the "resistance" of the line, and therefore of diminishing the strength of the current. When all the keys are untouched the resistance is least and the current strongest. On the other hand, when all the keys but the last are touched, the resistance is greatest and the current weakest. By this device it is easy to see that as the stylus or tracer sinks into a hollow of the gelatine, or rises over a height, the current in the line becomes stronger or weaker. At the distant station the current passes through a solenoid or hollow coil of wire connected to the earth and magnetises it, so as to pull the soft iron plug or "core" with greater or less force into its hollow interior. The up and down movement of the plug actuates a graving stylus or point through a lever, and engraves a

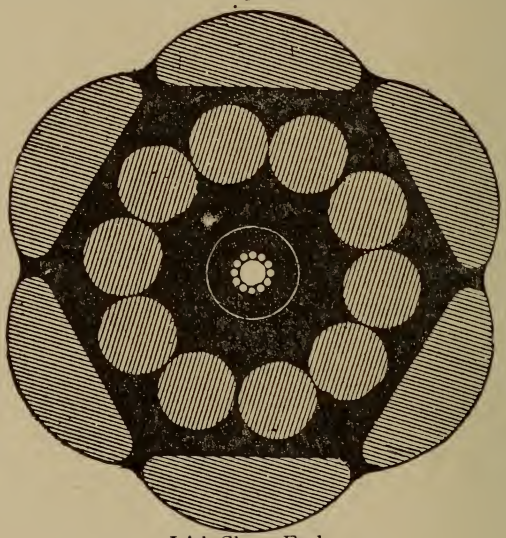
copy of the original gelatine trace on the surface of a wax or gelatine plate overlying another barrel or drum, which revolves at a rate corresponding to that of the barrel at the transmitting station. In this way a facsimile of the gelatine picture is produced at the distant station, and an electrotype or *cliché* of it can be made for printing purposes. The method is, in fact, a species of electric line graving, and Mr. Amstutz hopes to apply it to engraving on gold, silver, or any soft metal, not necessarily at a distance.

We know that an electric current in one wire can induce a transient current in a neighbouring wire, and the fact has been utilised in the United States by Phelps and others to send messages from moving trains. The signal currents are intermittent, and when they are passed through a conductor on the train they excite corresponding currents in a wire run along the track, which can be interpreted by the hum they make in a telephone. Experiments recently made by Mr. W. H. Preece for the Post Office show that with currents of sufficient strength and proper apparatus messages can be sent through the air for five miles or more by this method of induction.

We come now to the submarine telegraph, which differs in many respects from the overland telegraph. Obviously, since water and moist earth is a conductor, a wire to convey an electric current must be insulated if it is intended to lie at the bottom of the sea or buried underground. The best materials for the purpose yet discovered are gutta-percha and india-rubber, which are both flexible and very good insulators.

The first submarine cable was laid, across the Channel from Dover to Calais in 1851, and con-

sisted of a copper strand, coated with gutta-percha, and protected from injury by an outer sheath of hemp and iron wire. It is the general type of all the submarine cables which have been deposited since then in every part of the world. As a rule, the armour or sheathing is made heavier for shore water than it is for the deep sea, but the electrical portion, or "core," that



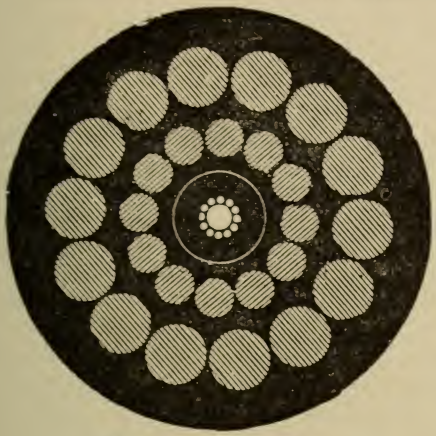
Irish Shore End.

FIG. 51.—SECTION OF THE 1894 ATLANTIC CABLE—ACTUAL SIZE.

is to say, the insulated conductor, is the same throughout.

The first Atlantic cable was laid in 1858 by Cyrus W. Field and a company of British capitalists, but it broke down, and it was not until 1866 that a new and successful cable was laid to re-

place it. Figure 51 represents various cross-sections of an Atlantic cable deposited in 1894.



Newfoundland Shore End.

Deep Sea.

Light Intermediate.

Heavy Intermediate.

SECTIONS OF THE 1894 ATLANTIC CABLE—ACTUAL SIZES—*continued.*

The inner star of twelve copper wires is the conductor, and the black circle round it is the gutta-

percha or insulator which keeps the electricity from escaping into the water. The core in shallow water is protected from the bites of teredoes by a brass tape, and the envelope or armour consists of hemp and iron wire preserved from corrosion by a covering of tape and a compound of mineral pitch and sand.

The circuit of a submarine line is essentially the same as that of a land line, except that the earth connection is usually the iron sheathing of the cable in lieu of an earth-plate. On a cable, however, at least a long cable, the instruments for sending and receiving the messages are different from those employed on a land line. A cable is virtually a Leyden jar or condenser, and the signal currents in the wire induce opposite currents in the water or earth. As these charges hold each

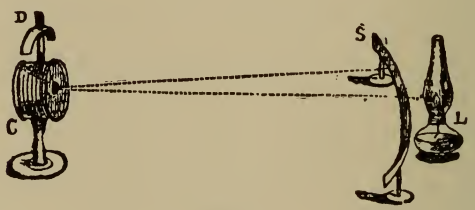



FIG. 52.

other the signals are retarded in their progress, and altered from sharp sudden jets to lagging undulations or waves, which tend to run together or coalesce. The result is that the separate signal currents which enter a long cable issue from it at the other end in one continuous current, with pulsations at every signal, that is to say, in a lapsing stream, like a jet of water flowing from a constricted spout. The receiving instrument must

be sufficiently delicate to manifest every pulsation of the current. Its indicator, in fact, must respond to every rise and fall of the current, as a float rides on the ripples of a stream.

Such an instrument is the beautiful "mirror" galvanometer of Lord Kelvin, Ex-President of the Royal Society, which we illustrate in figure 52, where *C* is a coil of wire with a small magnetic needle suspended in its heart, and *D* is a steel magnet supported over it. The needle (*M* figure 53) is made of watch spring cemented to the back of a tiny mirror the size of a half-dime which is hung by a single fibre of floss silk inside an air cell or chamber with a glass lens *G* in front, and the coil *C* surrounds it. A ray of light from a lamp *L* (figure 52) falls on the mirror, and is reflected back to a scale *S*, on which it makes a bright spot. Now, when the coil *C* is connected between the end of the cable and the earth, the signal current passing through it causes the tiny magnet to swing from side to side, and the mirror moving with it throws the beam up and down the scale. The operator sitting by watches the spot of light as it flits and flickers like a fire-fly in the darkness, and spells out the mysterious message.

FIG. 53.

A condenser joined in the circuit between the cable and the receiver, or between the receiver and the earth, has the effect of sharpening the waves of the current, and consequently of the signals. The double-current key, which reverses the poles of the battery and allows the signal currents to be of one length, that is to say, all "dots," is employed to send the message.

Another receiving instrument employed on

most of the longer cables is the siphon recorder of Lord Kelvin, shown in figure 54, which marks or writes the message on a slip of travelling paper. Essentially it is the inverse of the mirror instrument, and consists of a light coil of wire *S* suspended in the field between the poles of a strong magnet *M*. The coil is attached to a fine siphon (*P*) filled with ink, and sometimes kept in vibration by an induction coil so as to shake the ink in fine drops upon a slip of moving paper. The coil is connected between the cable and the earth, and, as the signal current passes through, it swings to one side or the other, pulling the siphon with it. The ink, therefore, marks a wavy line on the paper, which is in fact a

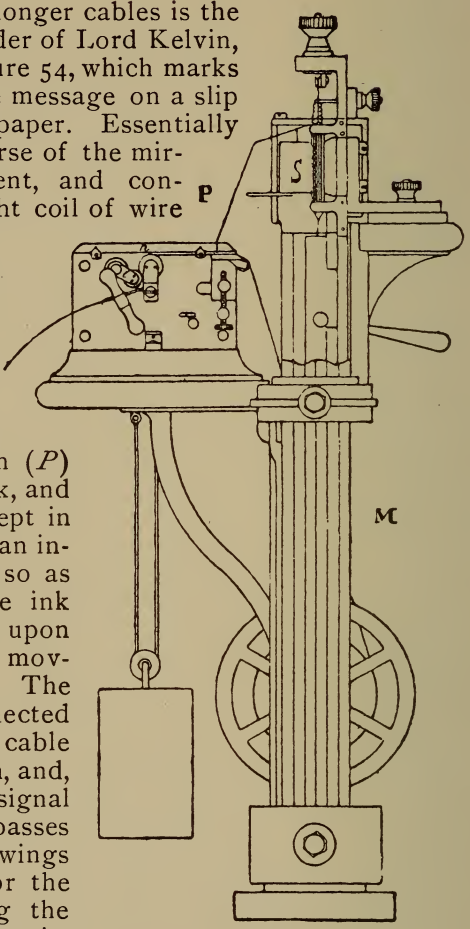



FIG. 54.

delineation of the rise and fall of the signal current and a record of the message. The dots in this case are represented by the waves above, and the "dashes" by the waves below the middle line, as may be seen in the following alphabet, which is a

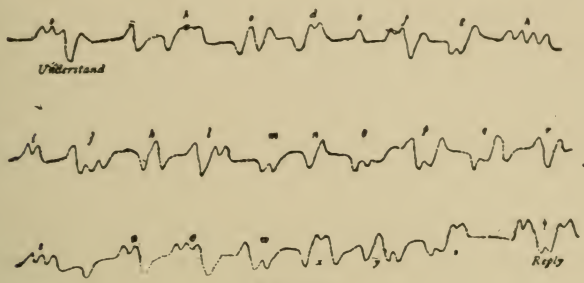


FIG. 55.

copy of one actually written by the recorder on a long submarine cable.

Owing to induction, the speed of signalling on long cables is much slower than on land lines of the same length, and only reaches from 25 to 45 words a minute on the Atlantic cables, or 30 to 50 words with an automatic sending-key; but this rate is practically doubled by employing the Muirhead duplex system of sending two messages, one from each end, at the same time.

The relation of the telegraph to the telephone is analogous to that of the lower animals and man. In a telegraph circuit, with its clicking key at one end and its chattering sounder at the other, we have, in fact, an apish forerunner of the exquisite telephone, with its mysterious microphone and oracular plate. Nevertheless, the telephone descended from the telegraph in a very indirect manner, if at all, and certainly not through the

sounder. The first practical suggestion of an electric telephone was made by M. Charles Bourseul, a French telegraphist, in 1854, but to all appearance nothing came of it. In 1860, however, Philipp Reis, a German schoolmaster, constructed a rudimentary telephone, by which music and a few spoken words were sent. Finally, in 1876, Mr. Alexander Graham Bell, a Scotchman, residing in Canada, and subsequently in the United States, exhibited a capable speaking telephone of his invention at the Centennial Exhibition, Philadelphia.

Figure 56 represents an outside view and section of the Bell telephone as it is now made, where *M* is a bar magnet having a small bobbin or coil of fine insulated wire *C* girdling one pole. In front of this coil there is a circular plate of soft iron capable of vibrating like a diaphragm or the drum of the ear. A cover shaped like a mouthpiece *O* fixes the diaphragm all round, and the wires *W W* serve to connect the coil in the circuit.

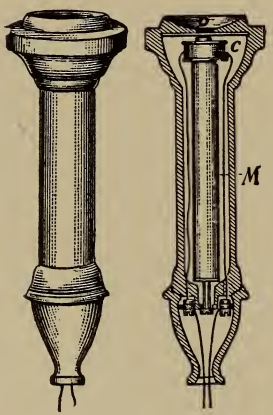


FIG. 56.

The soft iron diaphragm is, of course, magnetised by the induction of the pole, and would be attracted bodily to the pole were it not fixed by the rim, so that only its middle is free to move. Now, when a person speaks into the mouthpiece the sonorous waves impinge on the diaphragm

and make it vibrate in sympathy with them. Being magnetic, the movement of the diaphragm to and from the bobbin excites corresponding waves of electricity in the coil, after the famous experiment of Faraday (page 64). If this undulatory current is passed through the coil of a similar telephone at the far end of the line, it will, by a reverse action, set the diaphragm in vibration and reproduce the original sonorous waves. The result is, that when another person listens at the mouthpiece of the receiving telephone, he will hear a faithful imitation of the original speech.

The Bell telephone is virtually a small magneto-electric generator of electricity, and when two are joined in circuit we have a system for the transmission of energy. As the voice is the motive power, its talk, though distinct, is comparatively feeble, and further improvements were made before the telephone became as serviceable as it is now.

Edison, in 1877, was the first to invent a working telephone, which, instead of generating the current, merely controlled the strength of it, as the sluice of a mill-dam regulates the flow of water in the lead. Du Moncel had observed that powder of carbon altered in electrical resistance under pressure, and Edison found that lamp-black was so sensitive as to change in resistance under the impact of the sonorous waves. His transmitter consisted of a button or wafer of lamp-black behind a diaphragm, and connected in the circuit. On speaking to the diaphragm the sonorous waves pressed it against the button, and so varied the strength of the current in a sympathetic manner. The receiver of Edison was equally ingenious, and consisted of a cylinder of prepared chalk kept

in rotation and a brass stylus rubbing on it. When the undulatory current passed from the stylus to the chalk, the stylus slipped on the surface, and, being connected to a diaphragm, made it vibrate and repeat the original sounds. This "electro-motograph" receiver was, however, given up, and a combination of the Edison transmitter and the Bell receiver came into use.

At the end of 1877 Professor D. E. Hughes, a distinguished Welshman, inventor of the printing telegraph, discovered that any loose contact between two conductors had the property of transmitting sounds by varying the strength of an electric current passing through it. Two pieces of metal—for instance, two nails or ends of wire—when brought into a loose or crazy contact under a slight pressure, and traversed by a current, will transmit speech. Two pieces of hard carbon are still better than metals, and if properly adjusted will make the tread of a fly quite audible in a telephone connected with them. Such is the famous "microphone," by which a faint sound can be magnified to the ear.

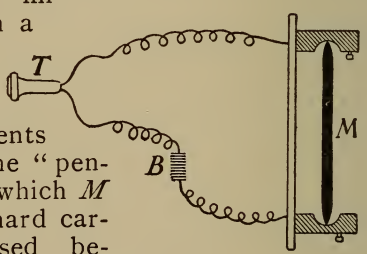


FIG. 57.

Figure 57 represents what is known as the "pencil" microphone, in which *M* is a pointed rod of hard carbon, delicately poised between two brackets of carbon, which are connected in circuit with a battery *B* and a Bell telephone *T*. The joints of rod and bracket are so sensitive that the current flowing across them is affected in strength

by the slightest vibration, even the walking of an insect. If, therefore, we speak near this microphone, the sonorous waves, causing the pencil to vibrate, will so vary the current in accordance with them as to reproduce the sounds of the voice in the telephone.

The true nature of the microphone is not yet known, but it is evident that the air or ether between the surfaces in contact plays an important part in varying the resistance, and, therefore, the current. In fact, a small "voltaic arc," not luminous, but dark, seems to be formed between the points, and the vibrations probably alter its length, and, consequently, its resistance. The fact that a microphone is reversible and can act as a receiver, though a poor one, tends to confirm this theory. Moreover, it is not unlikely that the slipping of the stylus in the electromotograph is due to a similar cause. Be this as it may, there can be no doubt that carbon powder and the lamp-black of the Edison button are essentially a cluster of microphones.

Many varieties of the Hughes microphone under different names are now employed as transmitters in connection with the Bell telephone. Figure 58 represents a simple micro-telephone circuit, where *M* is the Hughes microphone transmitter, *T* the Bell telephone receiver, *B* the battery, and *E E* the earth-plates; but sometimes a return wire is used in place of the "earth."

The line wire is usually of copper and its alloys, which are more suitable than iron, especially for long distances. Just as the signal currents in a submarine cable induce corresponding currents in the sea water which retard them, so the currents in a land wire induce corresponding

currents in the earth, but in aërial lines the earth is generally so far away that the consequent retardation is negligible except in fast working on long lines. The Bell telephone, however, is extremely sensitive, and this induction affects it so

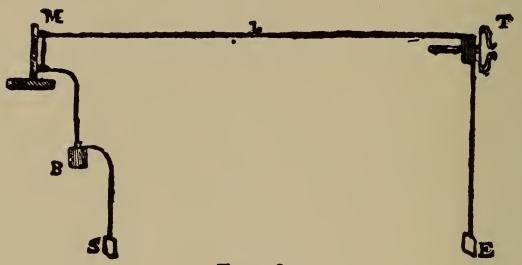



FIG. 58.

much that a conversation through one wire can be overheard on a neighbouring wire. Moreover, there is such a thing as "self-induction" in a wire —that is to say, a current in a wire tends to induce an opposite current in the same wire, which is practically equivalent to an increase of resistance in the wire. It is particularly observed at the starting and stopping of a current, and gives rise to what is called the "extra-spark" seen in breaking the circuit of an induction coil. It is also active in the vibratory currents of the telephone, and, like ordinary induction, tends to retard their passage. Copper being less susceptible of self-induction than iron, is preferred for trunk lines. The disturbing effect of ordinary induction is avoided by using a return wire or loop circuit, and crossing the going and coming wires so as to make them exchange places at intervals. Moreover, it is found that an induc-

tion coil in the telephone circuit, like a condenser in the cable circuit, improves the working, and hence it is usual to join the battery and transmitter with the primary wire, and the secondary wire with the line and the receiver.

The longest telephone line as yet made is that from New York to Chicago, a distance of 950 miles. It is made of thick copper wire, erected on cedar poles 35 feet above the ground.

Induction is so strong on submarine cables of 50 or 100 miles in length that the delicate waves of the telephone current are smoothed away, and the speech is either muffled or entirely stifled. Nevertheless, a telephone cable 20 miles long was laid between Dover and Calais in 1891, and another between Stranraer and Donaghadee more recently, thus placing Great Britain on speaking terms with France and other parts of the Continent.

Figure 59 shows a form of telephone apparatus employed in the United Kingdom. In it the transmitter and receiver, together with a call-bell, which are required at each end of the line, are neatly combined. The transmitter is a Blake microphone, in which the loose joint is a contact of platinum on hard carbon. It is fitted up inside the box, together with an induction coil, and *M* is the mouthpiece for speaking to it. The receiver is a pair of Bell telephones *T T*, which are detached from their hooks and held to the ear. A call-bell *B* serves to "ring up" the correspondent at the other end of the line.

Excepting private lines, the telephone is worked on the "exchange system"—that is to say, the wires running to different persons converge in a central exchange, where, by means of

an apparatus called a "switch-board," they are connected together for the purpose of conversation.

A telephone exchange would make an excel-

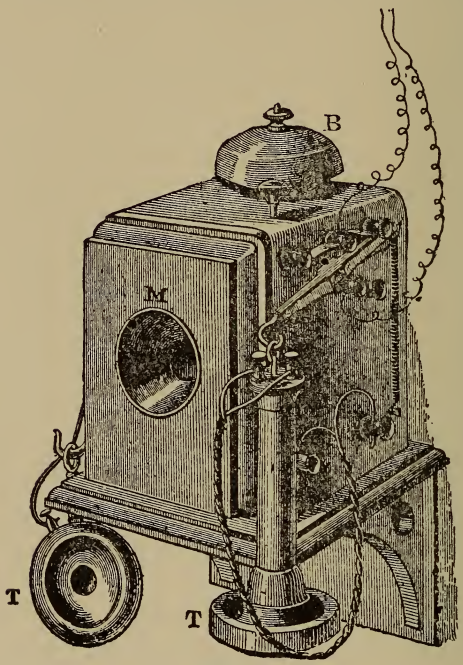



FIG. 59.

lent subject for the artist. He delights to paint us a row of Venetian bead-stringers or a band of Sevillian cigarette-makers, but why does he shirk a bevy of industrious girls working a telephone exchange? Let us peep into one of these retired haunts, where the modern Fates are cutting and

joining the lines of electric speech between man and man in a great city.

The scene is a long, handsome room or gallery, with a singular piece of furniture in the shape of an *L* occupying the middle. This is the switchboard, in which the wires from the offices and homes of the subscribers are concentrated like the nerves in a ganglion. It is known as the "multiple switchboard," an American invention, and is divided into sections, over which the operators preside. The lines of all the subscribers are brought to each section, so that the operator can cross-connect any two lines in the whole system without leaving her chair. Each section of the board is, in fact, an epitome of the whole, but it is physically impossible for a single operator to make all the connections of a large exchange, and the work is distributed amongst them. A multiplicity of wires is therefore needed to connect, say, two thousand subscribers. These are all concealed, however, at the back of the board, and in charge of the electricians. The young lady operators have nothing to do with these, and so much the better for them, as it would puzzle their minds a good deal worse than a ravelled skein of thread. Their duty is to sit in front of the board in comfortable seats at a long table and make the needful connections. The call-signal of a subscriber is given by the drop of a disc bearing his number. The operator then asks the subscriber by telephone what he wants, and on hearing the number of the other subscriber he wishes to speak with, she takes up a pair of brass plugs coupled by a flexible conductor and joins the lines of the subscribers on the switchboard by simply thrusting the plugs

into holes corresponding to the wires. The subscribers are then free to talk with each other undisturbed, and the end of the conversation is signalled to the operator. Every instant the call discs are dropping, the connecting plugs are thrust into the holes, and the girls are asking, "Hullo! hullo!" "Are you there?" "Who are you?" "Have you finished?" Yet all this constant activity goes on quietly, deftly—we might say elegantly—and in comparative silence, for the low tones of the girlish voices are soft and pleasing, and the harsher sounds of the subscriber are unheard in the room by all save the operator who attends to him.

## CHAPTER VII.

### ELECTRIC LIGHT AND HEAT.

The electric spark was, of course, familiar to the early experimenters with electricity, but the electric light, as we know it, was first discovered by Sir Humphrey Davy, the Cornish philosopher, in the year 1811 or thereabout. With the magic of his genius Davy transformed the spark into a brilliant glow by passing it between two points of carbon instead of metal. If, as in figure 60, we twist the wires (+ and —) which come from a voltaic battery, say of 20 cells, about two carbon pencils, and bring their tips together in order to start the current, then draw them a little apart, we shall produce an artificial or mimic star. A sheet of dazzling light, which is called the electric arc, is seen to bridge the gap. It is not a

true flame, for there is little combustion, but rather a nebulous blaze of silvery lustre in a bluish veil of heated air. The points of carbon are white-hot, and the positive is eaten away into a hollow or crater by the current, which violently tears its particles from their seat and whirls them into the fierce vortex of the arc. The negative remains pointed, but it is also worn away about half as fast as the positive. This wasting of the carbons tends to widen the arc too much and break the current, hence in arc lamps meant to yield the light for hours the sticks are made of a good length, and a self-acting mechanism feeds them forward to the arc as they are slowly consumed, thus maintaining the splendour of the illumination.

FIG. 60.

Many ingenious lamps have been devised by Serrin, Dubosq, Siemens, Brockie, and others, some regulating the arc by clockwork and electro-magnetism, or by thermal and other effects of the current. They are chiefly used for lighting halls and railway stations, streets and open spaces, search-lights and lighthouses. They are sometimes naked, but as a rule their brightness is tempered by globes of ground or opal glass. In search-lights a parabolic mirror projects all the rays in any one direction, and in lighthouses the arc is placed in the focus of the condensing lenses, and the beam is visible for at least twenty or thirty miles on clear nights. Very powerful arc

lights, equivalent to hundreds of thousands of candles, can be seen for 100 or 150 miles.

Figure 61 illustrates the Pilsen lamp, in which the positive carbon *G* runs on rollers *r r* through the hollow interior of two solenoids or coils of

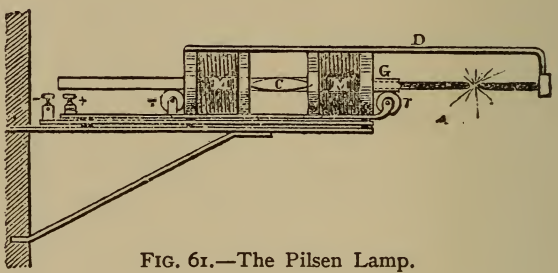



FIG. 61.—The Pilsen Lamp.

wire *M M'* and carries at its middle a spindle-shaped piece of soft iron *C*. The current flows through the solenoid *M* on its way to the arc, but a branch or shunted portion of it flows through the solenoid *M'*, and as both of these solenoids act as electromagnets on the soft iron *C*, each tending to suck it into its interior, the iron rests between them when their powers are balanced. When, however, the arc grows too wide, and the current therefore becomes too weak, the shunt solenoid *M'* gains a purchase over the main solenoid *M*, and, pulling the iron core towards it, feeds the positive carbon to the arc. In this way the balance of the solenoids is readjusted, the current regains its normal strength, the arc its proper width, and the light its brilliancy.

Figure 62 is a diagrammatic representation of the Brush arc lamp. *X* and *Y* are the line terminals connecting the lamp in circuit. On the

one hand, the current splits and passes around the hollow spools *H H'*, thence to the rod *N*

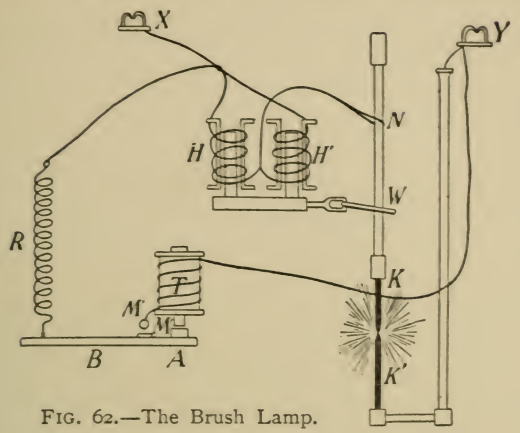



FIG. 62.—The Brush Lamp.

through the carbon *K*, the arc, the carbon *K'*, and thence through the lamp frame to *Y*. On the other hand, it runs in a resistance fine-wire coil around the magnet *T*, thence to *Y*. The operation of the lamp is as follows: *K* and *K*[1] being in contact, a strong current starts through the lamp energising *H* and *H'*, which suck in their core pieces *N* and *S*, lifting *C*, and by it the "washer-clutch" *W* and the rod *N* and carbon *K*, establishing the arc. *K* is lifted until the increasing resistance of the lengthening arc weakens the current in *H H'* and a balance is established. As the carbons burn away, *C* gradually lowers until a stop under *W* holds it horizontal and allows *N* to drop through *W*, and the lamp starts anew. If for any reason the resistance of the lamp becomes

too great, or the circuit is broken, the increased current through *T* draws up its armature, closing the contacts *M*, thus short-circuiting the lamp through a thick, heavy wire coil on *T*, which then keeps *M* closed, and prevents the dead lamp from interfering with the others on its line. Numerous modifications of this lamp are in very general use.

Davy also found that a continuous wire or stick of carbon could be made white-hot by sending a sufficient current through it, and this fact is the basis of the incandescent lamp now so common in our homes.

Wires of platinum, iridium, and other inoxidisable metals raised to incandescence by the current are useful in firing mines, but they are not quite suitable for yielding a light, because at a very high temperature they begin to melt. Every solid body becomes red-hot—that is to say, emits rays of red light, at a temperature of about 1000° Fahrenheit, yellow rays at 1300°, blue rays at 1500°, and white light at 2000°. It is found, however, that as the temperature of a wire is pushed beyond this figure the light emitted becomes far more brilliant than the increase of temperature would seem to warrant. It therefore pays to elevate the temperature of the filament as high as possible. Unfortunately the most refractory metals, such as platinum and alloys of platinum with iridium, fuse at a temperature of about 3450° Fahrenheit. Electricians have therefore forsaken metals, and fallen back on carbon for producing a light. In 1845 Mr. Staite devised an incandescent lamp consisting of a fine rod or stick of carbon rendered white-hot by the current, and to preserve the carbon from burning

in the atmosphere, he enclosed it in a glass bulb, from which the air was exhausted by an air pump. Edison and Swan, in 1878, and subsequently, went a step further, and substituted a filament or fine thread of carbon for the rod. The new lamp united the advantages of wire in point of form with those of carbon as a material. The Edison filament was made by cutting thin slips of bamboo and charring them, the Swan by carbonising linen fibre with sulphuric acid. It was subsequently found that a hard skin could be given to the filament by "flashing" it—that is to say, heating it to incandescence by the current in an atmosphere of hydro-carbon gas. The filament thus treated becomes dense and resilient.

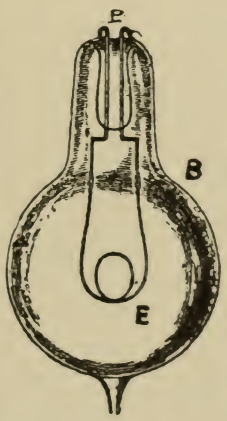


FIG. 63.

Figure 63 represents an ordinary glow lamp of the Edison-Swan type, where *E* is the filament, moulded into a loop, and cemented to two platinum wires or electrodes *P* penetrating the glass bulb *B*, which is exhausted of air.

Platinum is chosen because it expands and contracts with temperature about the same as glass, and hence there is little chance of the glass cracking through unequal stress. The vacuum in the bulb is made by a mercurial air pump of the Sprengel sort, and the pressure of air in it is only about one-millionth of an atmosphere. The bulb is fastened with a holder like that shown in figure 64, where two little hooks *H* con-

nected to screw terminals *T T* are provided to make contact with the platinum terminals of the lamp (*P*, figure 63), and the spiral spring, by pressing on the bulb, ensures a good contact.

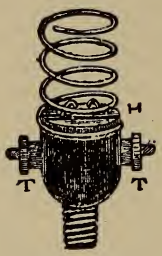


FIG. 64.

Fig. 65 is a cut of the ordinary Edison lamp and socket. One end of the filament is connected to the metal screw ferule at the base. The other end is attached to the metal button in the centre of the extreme bottom of the base. Screwing the lamp into the socket automatically connects the filament on one end to the screw, on the other to an insulated plate at the bottom of the socket.

The resistance of such a filament hot is about 200 ohms, and to produce a good light from it the battery or dynamo ought to give an electromotive force of at least 100 volts. Few voltaic cells or accumulators have an electromotive force of more than 2 volts, therefore we require a battery of 50 cells joined in series, each cell giving 2 volts, and the whole set 100 volts. The strength of current in the circuit must also be taken into account. To yield a good light such a lamp requires or "takes" about $\frac{1}{2}$ an ampère. Hence the cells must be chosen with regard to

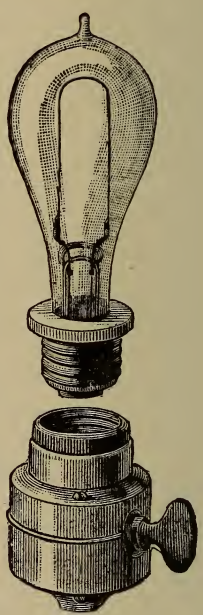


FIG. 65.

their size and internal resistance as well as to their kind, so that when the battery, in series, is connected to the lamp, the *resistance of the whole circuit*, including the filament or lamp, the battery itself, and the connecting wires shall give by Ohm's law a current of ½ an ampère. It will be understood that the current has the same strength in every part of the circuit, no matter how it is made up. Thus, if ½ of an ampère is flowing in the lamp, it is also flowing in the battery and wires. An Edison-Swan lamp of this model gives a light of about 15 candles, and is well-adapted for illuminating the interior of houses. The temperature of the carbon filament is about 3450° Fahr.—that is to say, the temperature at which platinum melts. Similar lamps of various sizes and shapes are also made, some equivalent to as many as 100 candles, and fitted for large halls or streets, others emitting a tiny beam like the spark of a glow-worm, and designed for medical examinations, or lighting flowers, jewels, and dresses in theatres or ball-rooms.

The electric incandescent lamp is pure and healthy, since it neither burns nor pollutes the air. It is also cool and safe, for it produces little heat, and cannot ignite any inflammable stuffs near it. Hence its peculiar merit as a light for colliers working in fiery mines. Independent of air, it acts equally well under water, and is therefore used by divers. Moreover, it can be fixed wherever a wire can be run, does not tarnish gilding, and lends itself to the most artistic decoration.

Electric lamps are usually connected in circuit on the series, parallel, and three-wire system.

The series system is shown in figure 66, where

the lamps *L L* follow each other in a row like beads on a string. It is commonly reserved for

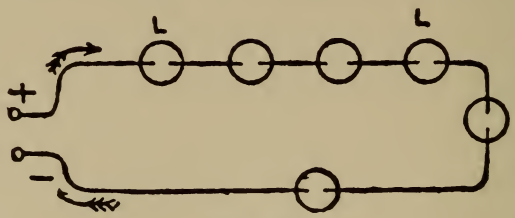



FIG. 66.

the arc lamp, which has a resistance so low that a moderate electromotive force can overcome the added resistance of the lamps, but, of course, if

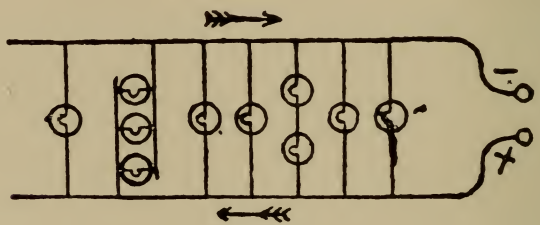



FIG. 67.

the circuit breaks at any point all the lamps go out.

The parallel system is illustrated in figure 67, where the lamps are connected between two main conductors cross-wise, like the steps of a ladder. The current is thus divided into cross channels, like water used for irrigating fields, and it is obvious that, although the circuit is broken at one point, say by the rupture of a filament, all the lamps do not go out.

Fig. 68 exhibits the Edison three-wire system, in which two batteries or dynamos are connected

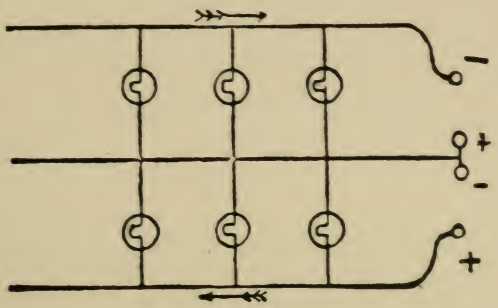



FIG. 68.

together in series, and a third or central main conductor is run from their middle poles. The plan saves a return wire, for if two generators had been used separately, four mains would have been necessary.

The parallel and three-wire systems in various groups, with or without accumulators as local reservoirs, are chiefly employed for incandescent lamps.

The main conductors conveying the current from the dynamos are commonly of stout copper insulated with air like telegraph wires, or cables coated with india-rubber or gutta-percha, and buried underground or suspended overhead. The branch and lamp conductors or "leads" are finer wires of copper, insulated with india-rubber or silk.

The current of an installation or section of one is made and broken at will by means of a "switch" or key turned by hand. It is simply a

series of metal contacts insulated from each other and connected to the conductors, with a sliding contact connected to the dynamo which travels over them. To guard against an excess of current on the lamps, "cut-outs," or safety-fuses, are inserted between the switch and the conductors, or at other leading points in the circuit. They are usually made of short slips of metal foil or wire, which melt or deflagrate when the current is too strong, and thus interrupt the circuit.

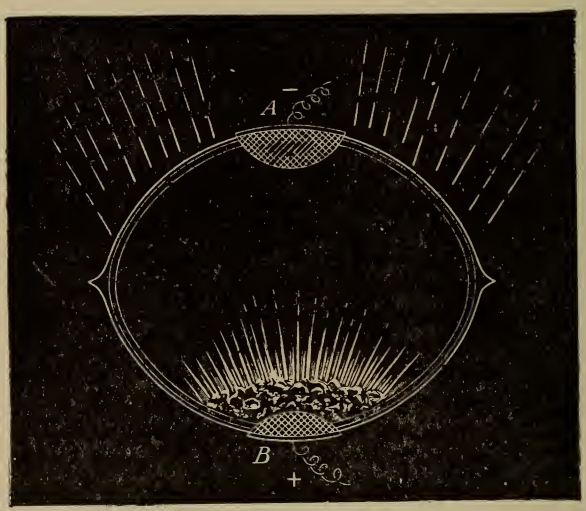



FIG. 69.—Electrical Phosphorescence.

There is some prospect of the luminosity excited in a vacuum tube by the alternating currents from a dynamo or an induction coil becoming an illuminant. Crookes has obtained exquisitely beautiful glows by the phosphorescence of gems

and other minerals in a vacuum bulb like that shown in figure 69, where *A* and *B* are the metal electrodes on the *outside* of the glass. A heap of diamonds from various countries emit red, orange, yellow, green, and blue rays. Ruby, sapphire, and emerald give a deep red, crimson, or lilac phosphorescence, and sulphate of zinc a magnificent green glow. Tesla has also shown that vacuum bulbs can be lit inside without any outside connection with the current, by means of an apparatus like that shown in figure 70, where *D* is an alternating dynamo, *C* a condenser, *P S* the primary and secondary coils of a sparking transformer, *T T* two metal sheets or plates, and *B B* the exhausted bulbs. The alternating or see-saw

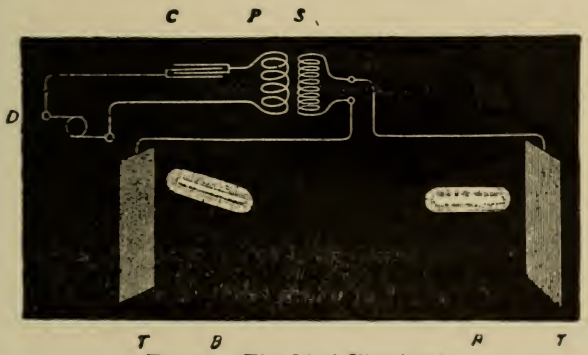



FIG. 70.—The Ideal Illuminant.

current in this case charges the condenser and excites the primary coil *P*, while the induced current in the secondary coil *S* charges the terminal plates *T T*. So long as the bulbs or tubes are kept within the space between the plates, they are filled with a soft radiance, and it is easy to

see that if these plates covered the opposite walls of a room, the vacuum lamps would yield a light in any part of it.

Electric heating bids fair to become almost as important as electric illumination. When the arc was first discovered it was noticed that platinum, gold, quartz, ruby, and diamond—in fine, the most refractory minerals—were melted in it, and ran like wax. Ores and salts of the metals were also vapourised, and it was clear that a powerful engine of research had been placed in the hands of the chemist. As a matter of fact, the temperature of the carbons in the arc is comparable to that of the Sun. It measures 5000 to 10,000° Fahrenheit, and is the highest artificial heat known. Sir William Siemens was among the first to make an electric furnace heated by the arc, which fused and vapourised metallic ores, so that the metal could be extracted from them. Aluminium, chromium, and other valuable metals are now smelted by its means, and rough brilliants such as those found in diamond mines and meteoric stones have been crystallised from the fumes of carbon, like hoar frost in a cold mist.

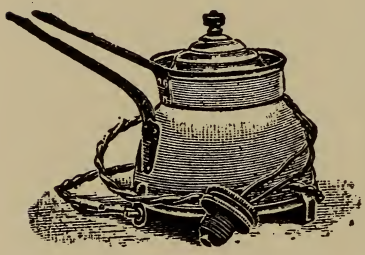


FIG. 71.

The electric arc is also applied to the welding of wires, boiler plates, rails, and other metal work, by heating the parts to be joined and fusing them together.

Cooking and heating by electricity are coming more and more into favour, owing to their clean-

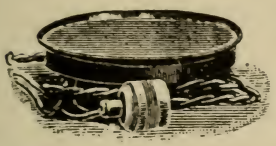


FIG. 72.

FIG. 73.

liness and convenience. Kitchen ranges, including ovens and grills, entirely heated by the electric current, are finding their way into the best houses and hotels. Most of these are based on the principle of incandescence, the current heating a fine wire or other conductor of high resistance in passing through it. Figure 71 represents an electric kettle of this sort, which requires no outside fire to boil it, since the current flows through fine wires of platinum or some highly resisting metal embedded in fireproof insulating cement in its bottom. Figures 72 and 73 are a sauce-pan and a flat-iron heated

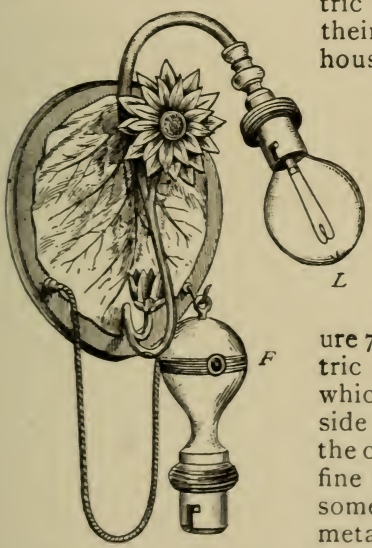



FIG. 74.

in the same way. Figure 74 is a cigar-lighter for smoking rooms, the fusee *F* consisting of short platinum wires, which become red-hot when it is unhooked, and at the same time the lamp *L* is automatically lit. Figure 75 is an electric radiator for heating rooms and passages, after the manner of stoves and hot water pipes. Quilts for beds, warmed by fine wires inside, have also been brought out, a constant temperature being maintained by a simple regulator, and it is not unlikely that personal clothing of the kind will soon be at the service of invalids and chilly mortals, more especially to make them comfortable on their travels.

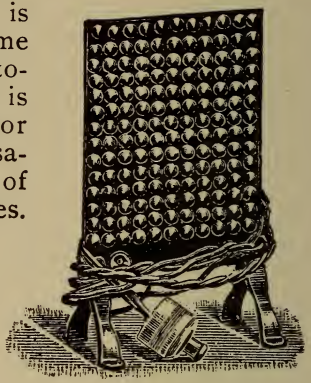


FIG. 75.

An ingenious device places an electric heater inside a hot water bag, thus keeping it at a uniform temperature for sick-room and hospital use.

## CHAPTER VIII.

### ELECTRIC POWER.

ON the discovery of electromagnetism (Chap. IV.), Faraday, Barlow, and others devised experimental apparatus for producing rotary motion from the electric current, and in 1831, Joseph

Henry, the famous American electrician, invented a small electromagnetic engine or motor. These early machines were actuated by the current from a voltaic battery, but in the middle of the century Jacobi found that a dynamo-electric generator can also work as a motor, and that by coupling two dynamos in circuit—one as a generator, the other as a motor—it was possible to transmit mechanical power to any distance by means of electricity. Figure 76 is a diagram of a simple circuit for the transmission of power, where *D* is the

FIG. 76.

technical symbol for a dynamo as a generator, having its poles (+ and −) connected by wire to the poles of *M*, the distant dynamo, as a motor. The generator *D* is driven by mechanical energy from any convenient source, and transforms it into electric energy, which flows through the circuit in the direction of the arrows, and, in traversing the motor *M*, is re-transformed into mechanical energy. There is, of course, a certain waste of energy in the process, but with good machines and conductors, it is not more than 10 to 25 per cent., or the "efficiency" of the installation is from 75 to 90 per cent.—that is to say, for every 100 horse-power put into the generator, from 75 to 90 horse-power are given out again by the motor.

It was not until 1870, when Gramme had improved the dynamo, that power was practically

transmitted in this way, and applied to pumping water, and other work. Since then great progress has been made, and electricity is now recognised, not only as a rival of steam, but as the best means of distributing steam, wind, water, or any other power to a distance, and bringing it to bear on the proper point.

The first electric railway, or, rather, tramway, was built by Dr. Werner von Siemens at Berlin in 1879, and was soon followed by many others. The wheels of the car were driven by an electric motor drawing its electricity from the rails, which were insulated from the ground, and being connected to the generator, served as conductors. It was found very difficult to insulate the rails, and keep the electricity from leaking to the ground, however, and at the Paris Electrical Exhibition of 1881, von Siemens made a short tramway in which the current was drawn from a bare copper conductor running on poles, like a telegraph wire, along the line.

The system will be understood from figure 77, where *L* is the overhead conductor joined to the positive pole of the dynamo or generator in the power house, and *C* is a rolling contact or trolley wheel travelling with the car and connected by the wire *W* to an electric motor *M* under the car, and geared to the axles. After passing through the motor the current escapes to the rail *R* by a brush or sliding contact *C'*, and so returns to the negative pole of the generator. A very general way is to allow the return current to escape to the rails through the wheels. Many tramways, covering thousands of miles, are now worked on this plan in the United States. At Bangor, Maine, a modification of it is in use whereby the

conductor is divided into sections, alternately connected to the positive and negative poles of two generators, coupled together as in the "three-wire system" of electric lighting (page 119),

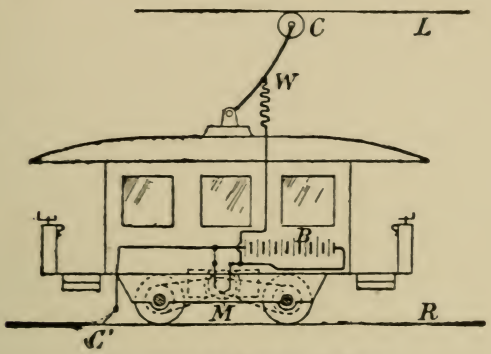



FIG. 77.—An Electric Railway.

their middle poles being joined to the earth—that is to say, the rails. It enables two cars to be run on the same line at once, and with a considerable saving of copper.

To make the car independent of the conductor *L* for a short time, as in switching, a battery of accumulators *B* may be added and charged from the conductor, so that when the motor is disconnected from the conductor, the discharge from the accumulator may still work it and drive the wheels.

Attempts have been made to run tramcars with the electricity supplied by accumulators alone, but the system is not economical owing to the dead weight of the cells, and the periodical trouble of recharging them at the generating station.

On heavy railroads worked by electricity the overhead conductor is replaced by a third rail along the middle of the track, and insulated from the ground. In another system the middle conductor is buried underground, and the current is tapped at intervals by the motor connecting with it for a moment by means of spring contacts as the car travels. In each case, however, the outer rails serve as the return conductors.

Another system puts one or both the conductors in a conduit underground, the trolley pole entering through a narrow slot similar to that used on cable roads.

The first electric carriages for ordinary roads were constructed in 1889 by Mr. Magnus Volk of Brighton. Figure 78 represents one of these made for the Sultan of Turkey, and propelled by a one-horse-power Immisch electric motor, geared to one of the hind wheels by means of a chain. The current for the motor was supplied by thirty "E. P. S." accumulators stowed in the body of the vehicle, and of sufficient power to give a speed of ten miles an hour. The driver steers with a hand lever as shown, and controls the speed by a switch in front of him.

Vans, bath chairs, and tricycles are also driven by electric motors, but the weight of the battery is a drawback to their use.

In or about the year 1839, Jacobi sailed an electric boat on the Neva, with the help of an electromagnetic engine of one horse-power, fed by the current from a battery of Grove cells, and in 1882 a screw launch, carrying several passengers, and propelled by an electric motor of three horse-power, worked by forty-five accumulators, was tried on the Thames. Being silent and

smokeless in its action, the electric boat soon came into favour, and there is now quite a flotilla

FIG. 78.—An Electric Carriage.

on the river, with power stations for charging the accumulators at various points along the banks.

Figure 79 illustrates the interior of a handsome electric launch, the *Lady Cooper*, built for the "E. P. S.," or Electric Power Storage Company. An electric motor in the after part of the hull is coupled directly to the shaft of the screw propeller, and fed by "E. P. S." accumulators in teak boxes lodged under the deck amidships. The screw is controlled by a switch, and the rudder by an ordinary helm. The cabin is seven feet long, and lighted by electric lamps. Alarm

signals are given by an electric gong, and a search-light can be brought into operation whenever it is desirable. The speed attained by the *Lady Cooper* is from ten to fifteen knots.

M. Goubet, a Frenchman, has constructed a submarine boat for discharging torpedoes and

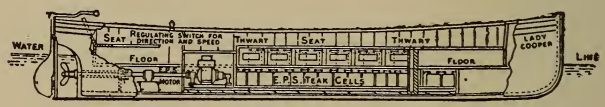



FIG. 79.—An Electric Launch.

exploring the sea bottom, which is propelled by a screw and an electric motor fed by accumulators. It can travel entirely under water, below the agitation of the waves, where sea-sickness is impossible, and the inventor hopes that vessels of the kind will yet carry passengers across the Channel.

The screw propeller of the Edison and Sim's torpedo is also driven by an electric motor. In this case the current is conveyed from the ship or fort which discharges the torpedo by an insulated conductor running off a reel carried by the torpedo, the "earth" or return half of the circuit being the sea-water.

All sorts of machinery are now worked by the electric motor—for instance, cranes, elevators, capstans, rivetters, lathes, pumps, chaff-cutters, and saws. Of domestic appliances, figure 80 shows an air propeller or ventilation fan, where *F* is a screw-like fan attached to the spindle of the motor *M*, and revolving with its armature. Figure 81 represents a Trouvé motor working a sewing-machine, where *N* is the motor which gears

with *P* the driving axle of the machine. Figure 82 represents a fine drill actuated by a Griscom motor. The motor *M* is suspended from a bracket *A B C* by the tackle *D E*, and transmits the rotation of its armature by a flexible shaft *S T* to the terminal drill *O*, which can be applied at any point, and is useful in boring teeth.

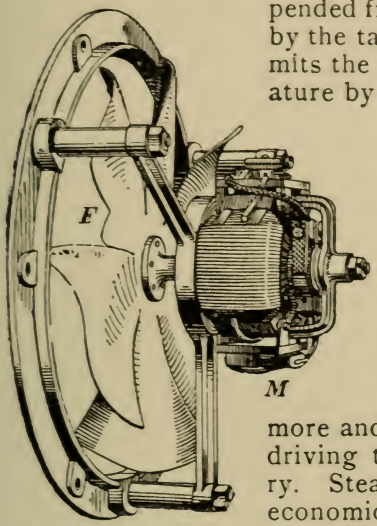



FIG. 80.—An Electric Fan.

Now that electricity is manufactured and distributed in towns and villages for the electric light, it is more and more employed for driving the lighter machinery. Steam, however, is more economical on a large scale, and still continues to be used in great factories for the heavier machinery. Nevertheless a day is coming when coal, instead of being carried by rail to distant works and cities, will be burned at the pit mouth, and its heat transformed by means of engines and dynamos into electricity for distribution to the surrounding country. I have shown elsewhere that peat can be utilised in a similar manner, and how the great Bog of Allen is virtually a neglected gold field in the heart of Ireland.* The sunshine of deserts, and perhaps the electricity of the atmosphere, but at all events the power of

* The *Nineteenth Century* for December 1894.

winds, waves, and waterfalls are also destined to whirl the dynamo, and yield us light, heat, or motion. Much has already been done in this direction. In 1891 the power of turbines driven by the

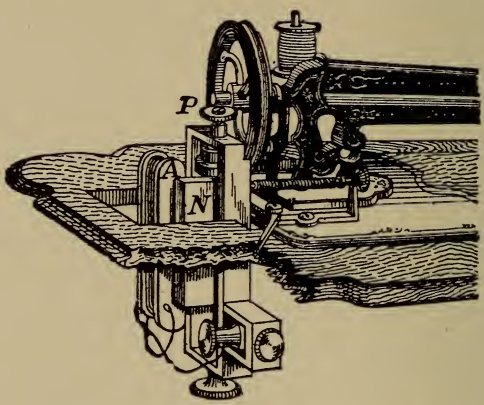



FIG. 81.—An Electric Sewing Machine.

Falls of Neckar at Lauffen was transformed into electricity, and transmitted by a small wire to the Electrical Exhibition of Frankfort-on-the-Main, 117 miles away. The city of Rome is now lighted from the Falls of Tivoli, 16 miles distant. The finest cataract in Great Britain, the Falls of Foyers, in the Highlands, which persons of taste and culture wished to preserve for the nation, is being sacrificed to the spirit of trade, and deprived of its waters for the purpose of generating electricity to reduce aluminium from its ores.

The great scheme recently completed for utilizing the power of Niagara Falls by means of electricity is a triumph of human enterprise which

outrivals some of the bold creations of Jules Verne.

When in 1678 the French missionaries La Salle and Hennepin discovered the stupendous cataract on the Niagara River between Lake Ontario and Lake Erie, the science of electricity was in its early infancy, and little more was known about the mysterious force which is performing miracles in our day than its manifestation on rubbed amber, sealing-wax, glass, and other bodies. Nearly a hundred years had still to pass ere Franklin should demonstrate the identity of the electric fire with lightning, and nearly another hundred before Faraday should reveal a mode of generating it from mechanical power. Assuredly, neither La Salle nor his contemporaries ever dreamed of a time when the water-power of the Falls would be distributed by means of electricity to produce light or heat and serve all manner of industries in the surrounding district. The awestruck Iroquois Indians had named the cataract "Oniagahra," or Thunder of the Waters, and believed it the dwelling-place of the Spirit of Thunder. This poetical name is none the less appropriate now that the modern electrician is preparing to draw his lightnings from

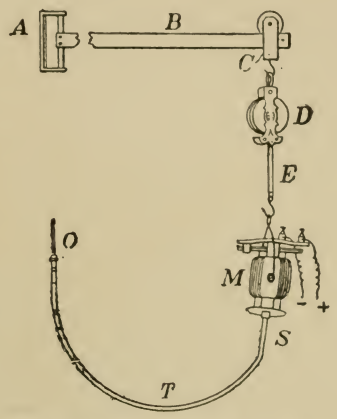



FIG. 82.—An Electric Drill.

its waters and compel the *genius loci* to become his willing bondsman.

The Falls of Niagara are situated about twenty-one miles from Lake Erie, and fourteen miles from Lake Ontario. At this point the Niagara River, nearly a mile broad, flowing between level banks, and parted by several islands, is suddenly shot over a precipice 170 feet high, and making a sharp bend to the north, pursues its course through a narrow gorge towards Lake Ontario. The Falls are divided at the brink by Goat Island, whose primeval woods are still thriving in their spray. The Horseshoe Fall on the Canadian side is 812 yards, and the American Falls on the south side are 325 yards wide. For a considerable distance both above and below the Falls the river is turbulent with rapids.

The water-power of the cataract has been employed from olden times. The French fur-traders placed a mill beside the upper rapids, and the early British settlers built another to saw the timber used in their stockades. By-and-by, the Stedman and Porter mills were established below the Falls; and subsequently, others which derived their water-supply from the lower rapids by means of raceways or leads. Eventually, an open hydraulic canal, three-fourths of a mile long, was cut across the elbow of land on the American side, through the town of Niagara Falls, between the rapids above and the verge of the chasm below the Falls, where, since 1874, a cluster of factories has arisen, which discharge their spent water over the cliff in a series of cascades almost rivalling Niagara itself. This canal, which only taps a mere drop from the ocean of power that is running to waste, has been utilised to the full; and

the decrease of water-privileges in the New England States, owing to the clearing of the forests and settlement of the country, together with the growth of the electrical industries, have led to a further demand on the resources of Niagara.

With the example of Minneapolis, which draws the power for its many mills from the Falls of St. Anthony, in the Mississippi River, before them, a group of far-seeing and enterprising citizens of Niagara Falls resolved to satisfy this requirement by the foundation of an industrial city in the neighbourhood of the Falls. They perceived that a better site could nowhere be found on the American Continent. Apart from its healthy air and attractive scenery, Niagara is a kind of half-way house between the East and West, the consuming and the producing States. By the Erie Canal at Tonawanda it commands the great waterway of the Lakes and the St. Lawrence. A system of trunk railways from different parts of the States and Canada are focussed there, and cross the river by the Cantilever and Suspension bridges below the Falls. The New York Central and Hudson River, the Lehigh Valley, the Buffalo, Rochester, and Pittsburgh, the Michigan Central, and the Grand Trunk of Canada, are some of these lines. Draining as it does the great lakes of the interior, which have a total area of 92,000 square miles, with an aggregate basin of 290,000 square miles, the volume of water in the Niagara River passing over the cataract every second is something like 300,000 cubic feet; and this, with a fall of 276 feet from the head of the upper rapids to the whirlpool rapids below, is equivalent to about nine million, or, allowing for waste in the turbines, say, seven million horse-power. Moreover, the

great lakes discharging into each other form a chain of immense reservoirs, and the level of the river being little affected by flood or drought, the supply of pure water is practically constant all the year round. Mr. R. C. Reid has shown that a rainfall of three inches in twenty-four hours over the basin of Lake Superior would take ninety days to run off into Lake Huron, which, with Lake Michigan, would take as long to overflow into Lake Erie; and, therefore, six months would elapse before the full effect of the flood was expended at the Falls.

The first outcome of the movement was the Niagara River Hydraulic Power and Sewer Company, incorporated in 1886, and succeeded by the Niagara Falls Power Company. The old plan of utilising the water by means of an open canal was unsuited to the circumstances, and the company adopted that of the late Mr. Thomas Evershed, divisional engineer of the New York State Canals. Like the other, it consists in tapping the river above the Falls, and using the pressure of the water to drive the number of turbines, then restoring the water to the river below the Falls; but instead of a surface canal, the tail-race is a hydraulic tunnel or underground conduit. To this end some fifteen hundred acres of spare land, having a frontage just above the upper rapids, was quietly secured at the low price of three hundred dollars an acre; and we believe its rise in value owing to the progress of the works is such that a yearly rental of two hundred dollars an acre can even now be got for it. This land has been laid out as an industrial city, with a residential quarter for the operatives, wharves along the river, and sidings or short lines to connect with the

trunk railways. In carrying out their purpose the company has budded and branched into other companies—one for the purchase of the land; another for making the railways; and a third, the Cataract Construction Company, which is charged with the carrying out of the engineering works, for the utilisation of the water-power, and is therefore the most important of all. A subsidiary company has also been formed to transmit by electricity a portion of the available power to the city of Buffalo, at the head of the Niagara River, on Lake Erie, some twenty miles distant. All these affiliated bodies are, however, under the directorate of the Cataract Construction Company; and amongst those who have taken the most active part in the work we may mention the president, Mr. E. D. Adams; Professor Coleman Sellers, the consulting engineer; and Professor George Forbes, F. R. S., the consulting electrical engineer, a son of the late Principal Forbes of Edinburgh.

In securing the necessary right of way for the hydraulic tunnel or in the acquisition of land, the Company has shown consummate tact. A few proprietors declined to accept its terms, and the Company selected a parallel route. Having obtained the right of way for the latter, it informed the refractory owners on the first line of their success, and intimated that the Company could now dispense with that. On this the sticklers professed their willingness to accept the original terms, and the bargain was concluded, thus leaving the Company in possession of the rights of way for two tunnels, both of which they propose to utilise.

The liberal policy of the directors is deserving

of the highest commendation. They have risen above mere "chauvinism," and instead of narrowly confining the work to American engineers, they have availed themselves of the best scientific counsel which the entire world could afford. The great question as to the best means of distributing and applying the power at their command had to be settled; and in 1890, after Mr. Adams and Dr. Sellers had made a visit of inspection to Europe, an International Commission was appointed to consider the various methods submitted to them, and award prizes to the successful competitors. Lord Kelvin (then Sir William Thomson) was the president, and Professor W. C. Unwin, the well-known expert in hydraulic engineering, the secretary, while other members were Professor Mascart of the Institute, a leading French electrician; Colonel Turretini of Geneva, and Dr. Sellers. A large number of schemes were sent in, and many distinguished engineers gave evidence before the Commission. The relative merits of compressed air and electricity as a means of distributing the power were discussed, and on the whole the balance of opinion was in favour of electricity. Prizes of two hundred and two hundred and fifty pounds were awarded to a number of firms who had submitted plans, but none of these were taken up by the Company. The impulse turbines of Messrs. Faesch & Piccard, of Geneva, who gained a prize of two hundred and fifty pounds, have, however, been adopted since. It is another proof of the determination of the Company to procure the best information on the subject, regardless of cost, that Professor Forbes had *carte blanche* to go to any part of the world and make a report

on any system of electrical distribution which he might think fit.

With the selection of electricity another question arose as to the expediency of employing continuous or alternating currents. At that time continuous currents were chiefly in vogue, and it speaks well for the sagacity and prescience of Professor Forbes that he boldly advocated the adoption of alternating currents, more especially for the transmission of power to Buffalo. His proposals encountered strong opposition, even in the highest quarters; but since then, partly owing to the striking success of the Lauffen to Frankfort experiment in transmitting power by alternating currents over a bare wire on poles a distance of more than a hundred miles, the directors and engineers have come round to his view of the matter, and alternating currents have been employed, at all events for the Buffalo line, and also for the chief supply of the industrial city. Continuous currents, flowing always in the same direction, like the current of a battery, can, it is true, be stored in accumulators, but they cannot be converted to higher or lower pressure in a transformer. Alternating currents, on the other hand, which see-saw in direction many times a second, cannot be stored in accumulators, but they can be sent at high pressure along a very fine wire, and then converted to higher or lower pressures where they are wanted, and even to continuous currents. Each kind, therefore, has its peculiar advantages, and both will be employed to some extent.

With regard to the engineering works, the hydraulic tunnel starts from the bank of the river where it is navigable, at a point a mile and

a half above the Falls, and after keeping by the shore, it cuts across the bend beneath the city of Niagara Falls, and terminates below the Suspension Bridge under the Falls at the level of the water. It is 6700 yards long, and of a horseshoe section, 19 feet wide by 21 feet high. It has been cut 160 feet below the surface through the limestone and shale, but is arched with brick, having rubble above, and at the outfall is lined on the invert or under side with iron. The gradient is 36 feet in the mile, and the total fall is 205 feet, of which 140 feet are available for use. The capacity of the tunnel is 100,000 horse-power. In the lands of the company it is 400 feet from the margin of the river, to which it is connected by a canal, which is over 1500 feet long, 500 feet wide at the mouth, and 12 feet deep.

Out of this canal, head-races fitted with sluices conduct the water to a number of wheel-pits 160 feet deep, which have been dug near the edge of the canal, and communicate below with the tunnel. At the bottom of each wheel-pit a 5000 horse-power Girard double turbine is mounted on a vertical shaft, which drives a propeller shaft rising to the surface of the ground; a dynamo of 5000 horse-power is fixed on the top of this shaft, and so driven by it. The upward pressure of the water is ingeniously contrived to relieve the foundation of the weight of the turbine shaft and dynamo. Twenty of these turbines, which are made by the I. P. Morris Company of Philadelphia, from the designs of Messrs. Faesch and Piccard, will be required to utilize the full capacity of the tunnel.

The company possesses a strip of land extending two miles along the shore; and in excavating

the tunnel a coffer-dam was made with the extracted rock, to keep the river from flooding the works. This dam now forms part of a system by which a tract of land has been reclaimed from the river. Part of it has already been acquired by the Niagara Paper Pulp Company, which is building gigantic factories, and will employ the tail-race or tunnel of the Cataract Construction Company. Wharfs for the use of ships and canal boats will also be constructed on this frontage. By land and water the raw materials of the West will be conveyed to the industrial town which is now coming into existence; grain from the prairies of Illinois and Dakota; timber from the forests of Michigan and Wisconsin; coal and copper from the mines of Lake Superior; and what not. It is expected that one industry having a seat there will attract others. Thus, the pulp mills will bring the makers of paper wheels and barrels; the smelting of iron will draw foundries and engine works; the electrical refining of copper will lead to the establishment of wire-works, cable factories, dynamo shops, and so on. Aluminum, too, promises to create an important industry in the future. In the meantime, the Cataract Construction Company is about to start an electrical factory of its own, which will give employment to a large number of men. It has also undertaken the water supply of the adjacent city of Niagara Falls. The Cataract Electric Company of Buffalo has obtained the exclusive right to use the electricity transmitted to that city, and the line will be run in a subway. This underground line will be more expensive to make than an overhead line, but it will not require to be renewed every eight to fifteen years, and it

will not be liable to interruption from the heavy gales that sweep across the lakes, or the weight of frozen sleet: moreover, it will be more easily inspected, and quite safe for the public. We should also add that, in addition to the contemplated duplicate tunnel of 100,000 horse-power, the Cataract Construction Company owns a concession for utilising 250,000 horse-power from the Horseshoe Falls on the Canadian side in the same manner. It has thus a virtual monopoly of the available water-power of Niagara, and the promoters have not the least doubt that the enterprise will be a great financial success. Already the Pittsburg Reduction Company have begun to use the electricity in reducing aluminum from the mineral known as bauxite, an oxide of the metal, by means of the electric furnace.

Another portion of the power is to be used to produce carbide of calcium for the manufacture of acetylene gas. At a recent electrical exhibition held in New York city a model of the Niagara plant was operated by an electric current brought from Niagara, 450 miles distant; and a collection of telephones were so connected that the spectator could hear the roar of the real cataract.

Thanks to the foresight of New York State and Canada, the scenery of the Falls has been preserved by the institution of public parks, and the works in question will do nothing to spoil it, especially as they will be free from smoke. Mr. Bogarts, State Engineer of New York, estimates that the water drawn from the river will only lower the mean depth of the Falls about two inches, and will therefore make no appreciable difference in the view. Altogether, the enterprise is something new in the history of the

world. It is not only the grandest application of electrical power, but one of the most remarkable feats in an age when romance has become science, and science has become romance.

## CHAPTER IX.

### MINOR USES OF ELECTRICITY.

THE electric "trembling bell," now in common use, was first invented by John Mirand in 1850. Figure 83 shows the scheme of the circuit, where

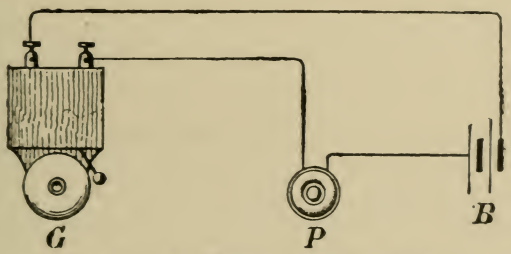



FIG. 83.—An Electric Trembling Bell.

*B* is a small battery, say two or three "dry" or Leclanché cells, joined by insulated wire to *P*, a press-button or contact key, and *G* an electro-magnetic gong or bell. On pressing the button *P*, a spring contact is made, and the current flowing through the circuit strikes the bell. The action of the contact key will be understood from figure 84, where *P* is the press-button removed to show the underlying mechanism, which is merely a metal spring *A* over a metal

plate *B*. The spring is connected by wire to a pole of the battery, and the plate to a terminal or binding screw of the bell, or *vice versâ*. When

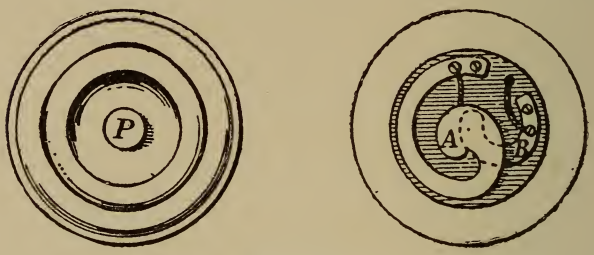



FIG. 84.

the button *P* is pressed by the finger the spring is forced against the plate, the circuit is made, and the bell rings. On releasing the button it springs back, the circuit is broken, and the bell stops.

Figure 85 shows the inner mechanism of the bell, which consists of a double-poled electromagnet *M*, having a soft iron armature *A* hinged on a straight spring or tongue *S*, with one end fixed, and the other resting against a screw contact *T*. The hammer *H* projects from the armature beside the edge of the gong *E*.

In passing through the instrument the current proceeds from one terminal, say that on the right, by the wire *W* to the screw contact *T*, and thence by the spring *S* through the bobbins of the electromagnet to the other terminal. The electromagnet attracts the armature *A*, and the hammer *H* strikes the gong; but in the act the spring *S* is drawn from the contact *T*, and the circuit is broken. Consequently the electromagnet, no

longer excited, lets the armature go, and the spring leaps back against the contact *T*, with-

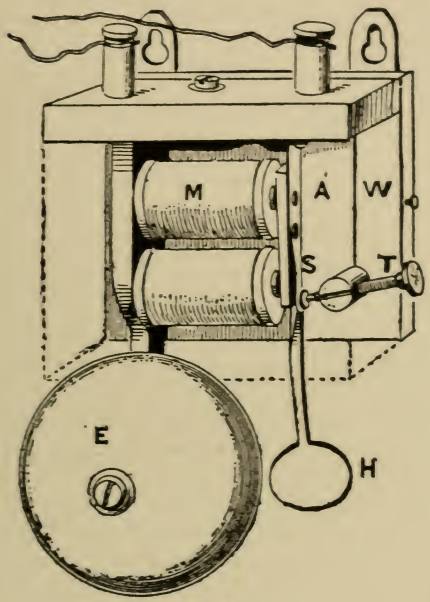



FIG. 85.

drawing the hammer from the gong. But the instrument is now as it was at first, the current again flows, and the hammer strikes the gong, only to fly back a second time. In this way, as long as the button is pressed by the operator, the hammer will continue to tap the bell and give a ringing sound. Press-buttons are of various patterns, and either affixed to the wall or inserted in the handle of an ordinary bell-pull, as shown in figure 86.

The ordinary electric bell actuated by a battery is liable to get out of order owing to the battery spending its force, or to the contacts becoming dirty. Magneto-electric bells have, therefore, been introduced of late years. With these no battery or interrupting contacts are required, since the bell-pull or press-button is made in the form of a small dynamo which generates the current when it is pulled or pushed. Figure 87 illustrates a form of this apparatus, where *M P* is the bell-pull and *B* the bell, these being connected by a double wire *W*, to convey the current. The bell-pull consists of a horseshoe magnet *M*, having a bobbin of insulated wire between its poles, and mounted on a spindle. When the key *P* is turned round by the hand, the bobbin moves in the magnetic field between the poles of the magnet, and the current thus generated circulates in the wires *W*, and passing through an electro-magnet under the bell, attracts its armature, and strikes the hammer on the bell. Of course the bell may be placed at any distance from the generator. In other types the current is generated and the bell rung by the act of pulling, as in a common house-bell.

FIG. 86.

Electric bells in large houses and hotels are usually fitted up with indicators, as shown in figure 88, which tell the room from which the call proceeds. They are serviceable as instantaneous signals, annunciators, and alarms in many

different ways. An outbreak of fire can be announced by causing the undue rise of tempera-

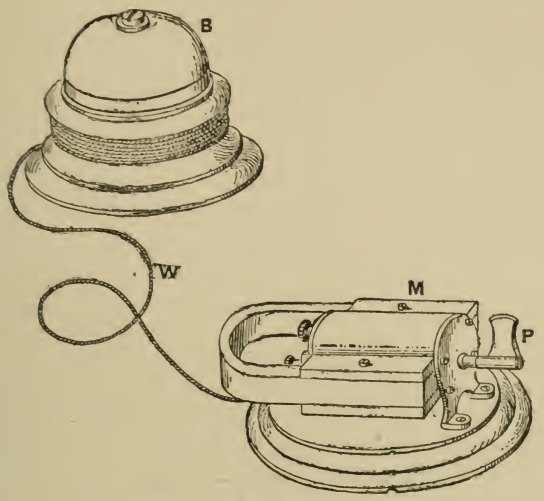



FIG. 87.

ture to melt a piece of tallow or fusible metal, and thus release a weight, which falls on a press-button, and closes the circuit of an electric bell. Or, the rising temperature may expand the mercury in a tube like that of a thermometer until it connects two platinum wires fused through the glass and in circuit with a bell. Some employ a curving bi-metallic spring to make the necessary contact. The spring is made by soldering strips of brass and iron back to back, and as these metals expand unequally when heated, the spring is deformed, and touches the contact which is connected in the circuit, thus permitting the cur-

rent to ring the bell. A still better device, however, is a small box containing a thin metallic diaphragm, which expands with the heat, and sagging in the centre, touches a contact screw, thus completing the circuit, and allowing the current to pass.

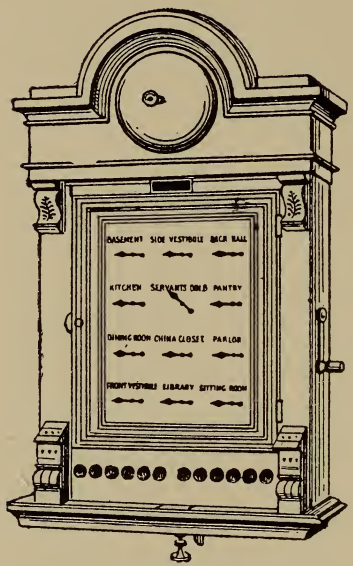

BASEMENT SIDE VESTIBULE BACK HALL
KITCHEN SERVANTS DINING PANTRY
DINING ROOM CHINA CLOSET PARLOR
FRONT VESTIBULE LIBRARY SITTING ROOM

FIG. 88.

These automatic or self-acting fire-alarms can, of course, be connected in the circuit of the ordinary street fire-alarms, which are usually worked by pulling a handle to make the necessary contact.

From what has been said, it will be easy to understand how the stealthy entrance of burglars into a house can be announced by an electric bell or warning lamp. If press-buttons or contact-keys are placed on the sashes of the windows, the posts of the door, or the treads of the stair, so that when the window or door is opened, or the tread bends under the footstep, an electric circuit is closed, the alarm will be given. Of course, the connections need only be arranged when the device is wanted. Shops and offices can be guarded by making the current show a

red light from a lamp hung in front of the premises, so that the night watchman can see it on his beat. This can readily be done by adjusting an electromagnet to drop a screen of red glass before the flame of the lamp. Safes and showcases forcibly opened can be made to signal the fact, and recently in the United States a thief was photographed by a flashlight kindled in this way, and afterwards captured through the likeness.

The level of water in cisterns and reservoirs can be told in a similar manner by causing a float to rise with the water and make the required contact. The degree of frost in a conservatory can also be announced by means of the mercury "thermostat," already described, or some equivalent device. There are, indeed, many actual or possible applications of a similar kind.

The Massey log is an instrument for telling the speed of a ship by the revolutions of a "fly" as it is towed through the water, and by making the fly complete a circuit as it revolves the number of turns a second can be struck by a bell on board. In one form of the "electric log," the current is generated by the chemical action of zinc and copper plates attached to the log, and immersed in the sea water, and in others provided by a battery on the ship.

Captain M'Evoy has invented an alarm for torpedoes and torpedo boats, which is a veritable watchdog of the sea. It consists of an iron bell-jar inverted in the water, and moored at a depth below the agitation of the waves. In the upper part of the jar, where the pressure of the air keeps back the water, there is a delicate needle contact in circuit with a battery and an electric

bell or lamp, as the case may be, on the shore. Waves of sound passing through the water from the screw propeller of the torpedo, or, indeed, any ship, make and break the sensitive contact, and ring the bell or light the lamp. The apparatus is intended to alarm a fleet lying at anchor or a port in time of war.

Electricity has also been employed to register the movements of weathercocks and anemometers. A few years ago it was applied successfully to telegraph the course marked by a steering compass to the navigating officer on the bridge. This was done without impeding the motion of the compass card by causing an electric spark to jump from a light pointer on the card to a series of metal plates round the bowl of the compass, and actuate an electric alarm.

The "Domestic Telegraph," an American device, is a little dial apparatus by which a citizen can signal for a policeman, doctor, messenger, or carriage, as well as a fire engine, by the simple act of setting a hand on the dial.

Alexander Bain was the first to drive a clock with electricity instead of weights, by employing a pendulum having an iron bob, which was attracted to one side and the other by an electromagnet, but as its rate depends on the constancy of the current, which is not easy to maintain, the invention has not come into general use. The "butterfly clock" of Lemoine, which we illustrate in figure 89, is an improved type, in which the bob of soft iron *P* swings to and fro over the poles of a double electro magnet *M* in circuit with a battery and contact key. When the rate is too slow the key is closed, and a current passing through the electromagnet pulls on the pendu-

lum, thus correcting the clock. This is done by the ingenious device of Hipp, shown in figure 90, where *M* is the electromagnet, *P* the iron bob, from which projects a wire bearing a light vane *B* of mica in the shape of a butterfly. As the bob swings the wire drags over the hump of the metal spring *S*, and when the bob is going too slowly the wire thrusts the spring into contact with another spring *T* below, thus closing the circuit, and sending a current through the magnet *M*, which attracts the bob and gives a fillip to the pendulum.

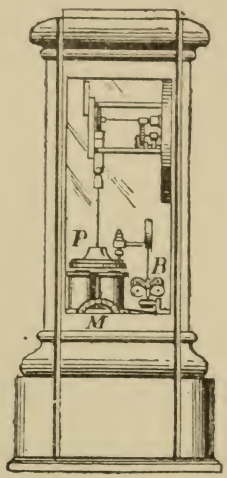



FIG. 89.—The Electric "Butterfly" Clock.

Local clocks controlled from a standard clock by electricity have been more successful in practice, and are employed in several towns—for example, Glasgow. Behind local dials are electromagnets which, by means of an armature working a frame and ratchet wheel, move the hands forward every minute or half-minute as the current is sent from the standard clock.

The electrical chronograph is an instrument for measuring minute intervals of time by means of a stylus tracing a line on a band of travelling paper or a revolving barrel of smoked glass. The current, by exciting an electromagnet, jerks the stylus, and the interval between two jerks is found from the length of the trace between them

and the speed of the paper or smoked surface. Retarded clocks are sometimes employed as electric meters for registering the consumption of electricity. In these the current to be measured flows through a coil beneath the bob of the pendulum, which is a magnet, and thus affects the

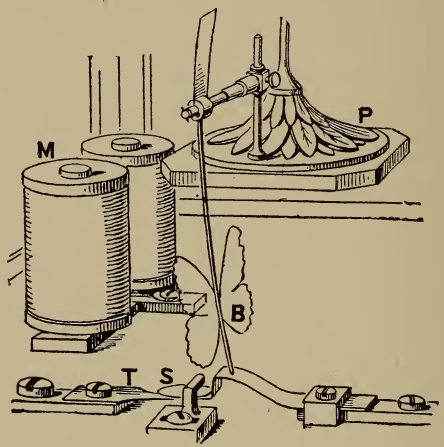



FIG. 90.

rate. In other meters the current passes through a species of galvanometer called an ampère meter, and controls a clockwork counter. In a third kind of meter the chemical effect of the current is brought into play—that of Edison, for example, decomposing sulphate of copper, or more commonly of zinc.

The electric light is now used for signalling and advertising by night in a variety of ways. Incandescent lamps inside a translucent balloon, and their light controlled by a current key, as in

a telegraph circuit, so as to give long and short flashes, according to the Morse code, are employed in the army. Signals at sea are also made by a set of red and white glow-lamps, which are combined according to the code in use. The powerful arc lamp is extremely useful as a "search light," especially on men-of-war and fortifications, and it has also been tried in signalling by projecting the beam on the clouds by way of a screen, and eclipsing it according to a given code.

In 1879, Professor Graham Bell, the inventor of the speaking telephone, and Mr. Summer Tainter, brought out an ingenious apparatus called the photophone, by which music and speech were sent along a beam of light for several hundred yards. The action of the photophone is based on the peculiar fact observed in 1873 by Mr. J. E. Mayhew, that the electrical resistance of crystalline selenium diminishes when a ray of light falls upon it. Figure 91 shows

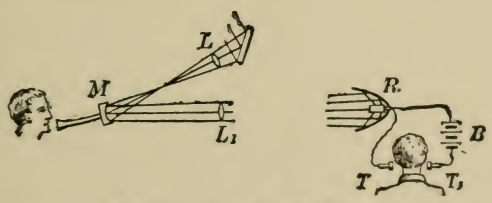



FIG. 91.—The Photophone.

how Bell and Tainter utilised this property in the telephone. A beam of sun or electric light, concentrated by a lens *L*, is reflected by a thin mirror *M*, and after traversing another lens *L*, travels to the parabolic reflector *R*, in the focus of

which there is a selenium resistance in circuit with a battery $B$ and two telephones $T$ $T'$. Now, when a person speaks into the tube at the back of the mirror $M$, the light is caused to vibrate with the sounds, and a wavering beam falls on the selenium, changing its resistance to the current. The strength of the current is thus varied with the sonorous waves, and the words spoken by the transmitter are heard in the telephones by the receiver. The photophone is, however, more of a scientific toy than a practical instrument.

Becquerel, the French chemist, found that two plates of silver freshly coated with silver from a solution of chloride of silver and plunged into water, form a voltaic cell which is sensitive to light. This can be seen by connecting the plates through a galvanometer, and allowing a ray of light to fall upon them. Other combinations of the kind have been discovered, and Professor Minchin, the Irish physicist, has used one of these cells to measure the intensity of starlight.

The "induction balance" of Professor Hughes is founded on the well-known fact that a current passing in one wire can induce a sympathetic current in a neighbouring wire. The arrangement will be understood from figure 92, where $P$ and $P_1$ are two similar coils or bobbins of thick wire in circuit with a battery $B$ and a microphone $M$, while $S$ and $S_1$ are two similar coils or bobbins of fine wire in circuit with a telephone $T$. It need hardly be said that when the microphone $M$ is disturbed by a sound, the current in the primary coils $P$ $P_1$ will induce a corresponding current in the secondary coils $S$ $S_1$; but the

coils $S$ $S_1$ are so wound that the induction of $P$ on $S$ neutralises the induction of $P_1$ on $S_1$, and no current passes in the secondary circuit, hence no sound is heard in the telephone. When, how-

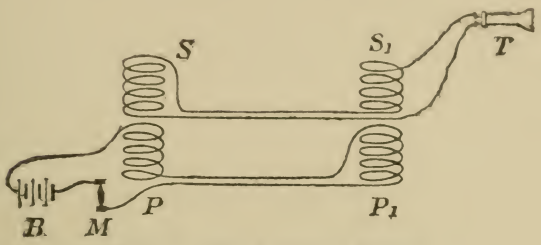



FIG. 92.—The Induction Balance.

ever, this balance of induction is upset by bringing a piece of metal—say, a coin—near one or other of the coils $S$ $S_1$, a sound will be heard in the telephone.

The induction balance has been used as a "Sonometer" for measuring the sense of hearing, and also for telling base coins. The writer devised a form of it for "divining" the presence of gold and metallic ores which has been applied by Captain M'Evoy in his "submarine detector" for exploring the sea bottom for lost anchors and sunken treasure. When President Garfield was shot, the position of the bullet was ascertained by a similar arrangement.

The microphone as a means of magnifying feeble sounds has been employed for localising the leaks in water pipes and in medical examinations. Some years ago it saved a Russian lady from premature burial by rendering the faint beating of her heart audible.

Edison's electric pen is useful in copying letters. It works by puncturing a row of minute holes along the lines of the writing, and thus producing a stencil plate, which, when placed over a clean sheet of paper and brushed with ink, gives a duplicate of the writing by the ink penetrating the holes to the paper below. It is illustrated in figure 93, where *P* is the pen, consisting of a hol-

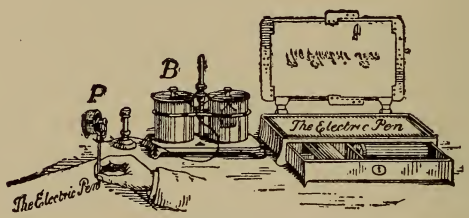



FIG. 93.—The Electric Pen.

low stem in which a fine needle actuated by the armature of a small electromagnet plies rapidly up and down and pierces the paper. The current is derived from a small battery *B*, and an inking roller like that used in printing serves to apply the ink.

In 1878 Mr. Edison announced his invention of a machine for the storage and reproduction of speech, and the announcement was received with a good deal of incredulity, notwithstanding the partial success of Faber and others in devising mechanical articulators. The simplicity of Edison's invention when it was seen and heard elicited much admiration, and although his first instrument was obviously imperfect, it was nevertheless regarded as the germ of something better. If the words spoken into the instrument were heard in the first

place, the likeness of the reproduction was found to be unmistakable. Indeed, so faithful was the replica, that a member of the Academy of Sciences, Paris, stoutly maintained that it was due to ventriloquism or some other trickery. It was evident, however, that before the phonograph could become a practical instrument, further improvements in the nicety of its articulation were required. The introduction of the electric light diverted Mr. Edison from the task of improving it, although he does not seem to have lost faith in his pet invention. During the next ten years he accumulated a large fortune, and was the principal means of introducing both electric light and power to the world at large. This done, however, he returned to his earlier love, and has at length succeeded in perfecting it so as to redeem his past promises and fulfil his hopes regarding it.

The old instrument consisted, as is well known, of a vibrating tympan or drum, from the centre of which projected a steel point or stylus, in such a manner that on speaking to the tympan its vibrations would urge the stylus to dig into a sheet of tinfoil moving past its point. The foil was supported on a grooved barrel, so that the hollow of the groove behind it permitted the foil to give under the point of the stylus, and take a corrugated or wavy surface corresponding to the vibrations of the speech. Thus recorded on a yielding but somewhat stiff material, these undulations could be preserved, and at a future time made to deflect the point of a similar stylus, and set a corresponding diaphragm or tympan into vibration, so as to give out the original sounds, or an imitation of them.

Tinfoil, however, is not a very satisfactory material on which to receive the vibrations in the first place. It does not precisely respond to the movements of the marking stylus in taking the impression, and does not guide the receiving stylus sufficiently well in reproducing sounds. Mr. Edison has therefore adopted wax in preference to it; and instead of tinfoil spread on a grooved support, he now employs a cylinder of wax to take the print of the vibrations. Moreover, he no longer uses the same kind of diaphragm to print and receive the sounds, but employs a more delicate one for receiving them. The marking cylinder is now kept in motion by an electric motor, instead of by hand-turning, as in the earlier instrument.

The new phonograph, which we illustrate in figure 94, is about the size of an ordinary sewing machine, and is of exquisite workmanship, the performance depending to a great extent on the perfection and fitness of the mechanism. It consists of a horizontal spindle *S*, carrying at one end the wax cylinder *C*, on which the sonorous vibrations are to be imprinted. Over the cylinder is supported a diaphragm or tympan *T*, provided with a conical mouthpiece *M* for speaking into. Under the tympan there is a delicate needle or stylus, with its point projecting from the centre of the tympan downwards to the surface of the wax cylinder, so that when a person speaks into the mouthpiece, the voice vibrates the tympan and drives the point of the stylus down into the wax, making an imprint more or less deep in accordance with the vibrations of the voice. The cylinder is kept revolving in a spiral path, at a uniform speed, by means of an electric motor *E*.

fitted with a sensitive regulator and situated at the base of the machine. The result is that a deli-

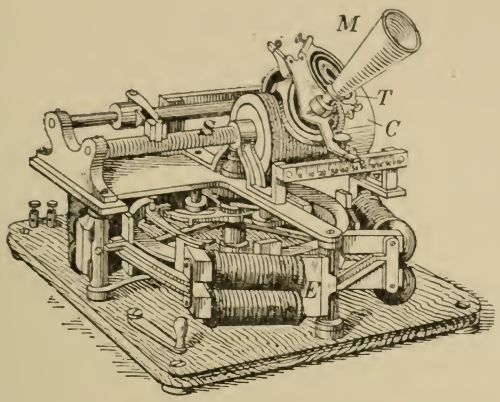



FIG. 94.—The Phonograph.

cate and ridgy trace is cut in the surface of wax along a spiral line. This is the sound record, and by substituting a finer tympan for the one used in producing it, the ridges and inequalities of the trace can be made to agitate a light stylus resting on them, and cause it to set the delicate tympan into vibrations corresponding very accurately to those of the original sounds. The tympan employed for receiving is made of gold-beater's skin, having a stud at its centre and a springy stylus of steel wire. The sounds emitted by this device are almost a whisper as compared to the original ones, but they are faithful in articulation, which is the main object, and they are conveyed to the ear by means of flexible hearing-tubes.

These tympans are interchangeable at will,

and the arm which carries them is also provided with a turning tool for smoothing the wax cylinder prior to its receiving the print. The cylinders are made of different sizes, from 1 to 8 inches long and 4 inches in diameter. The former has a storage capacity of 200 words. The next in size has twice that, or 400 words, and so on. Mr. Edison states that four of the large 8-inch cylinders can record all "Nicholas Nickleby," which could therefore be automatically read to a private invalid or to a number of patients in a hospital simultaneously, by means of a bunch of hearing-tubes. The cylinders can be readily posted like letters, and made to deliver their contents *vivâ voce* in a duplicate phonograph, every tone and expression of the writer being rendered with more or less fidelity. The phonograph has proved serviceable in recording the languages and dialects of vanishing races, as well as in teaching pronunciation.

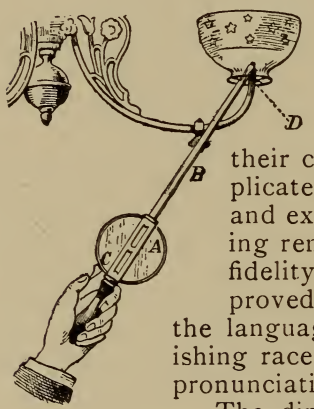



FIG. 95.—An Electric Gas Lighter.

The dimensions, form, and consequent appearance of the present commercial American phonograph are quite different from that above described, but the underlying principles and operations are identical.

A device for lighting gas by the electric spark is shown in figure 95, where *A* is a flat vulcanite box, containing the apparatus which generates the electricity, and a stem or pointer *B*, which

applies the spark to the gas jet. The generator consists of a small "influence" machine, which is started by pressing the thumb-key *C* on the side of the box. The rotation of a disc inside the box produces a supply of static electricity, which passes in a stream of sparks between two contact-points in the open end of the stem *D*. The latter is tubular, and contains a wire insulated from the metal of the tube, and forming with the tube the circuit for the electric discharge. The handle enables the contrivance to be readily applied. The apparatus is one of the few successful practical applications of static electricity.

Other electric gas-lighters consist of metal points placed on the burner, so that the electric spark from a small induction coil or dynamo kindles the jet.

A platinum wire made white-hot by the passage of a current is sometimes used to light lamps, as shown in figure 96, where *W* is a small spiral of platinum connected in circuit with a generator by the terminals *T T*. When the lamp *L* is pressed against the button *B* the wire glows and lights it.

Explosives, such as gunpowder and guncotton, are also ignited by the electric spark from an induction coil or the incandescence of a wire. Figure 97 shows the interior of an ordinary electric fuse for blasting or exploding underground mines. It consists of a box of wood or metal primed with gunpowder or other explosive, and a platinum wire *P* soldered to a pair of stout copper wires *W*, insulated with guttapercha. When the current is sent along these wires, the platinum glows and ignites the explosive. Detonating fuses are primed with fulminate of mercury.

Springs for watches and other purposes are tempered by heating them with the current and quenching them in a bath of oil.

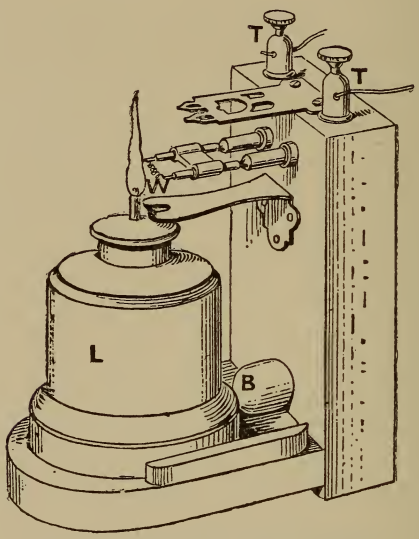



FIG. 96.—An Electric Lamp Lighter.

Electrical cautery is performed with an incandescent platinum wire in lieu of the knife, especially for such operations as the removal of the tongue or a tumour.

It was known to the ancients that a fish called a torpedo existed in the Mediterranean which was capable of administering a shock to persons and benumbing them. The torpedo, or "electric ray," is found in the Atlantic as well as the Mediterranean, and is allied to the skate. It has an electric organ composed of 800 or 1000 polygonal

cells in its head, and the discharge, which appears to be a vibratory current, passes from the

FIG. 97.—An Electric Fuse.

back or positive pole to the belly or negative pole through the water. The *gymotus*, or Surinam eel, which attains a length of five or six feet, has an electric organ from head to tail, and can give a shock sufficient to kill a man. Humboldt has left a vivid picture of the frantic struggles of wild horses driven by the Indians of Venezuela into the ponds of the savannahs infested by these eels, in order to make them discharge their thunderbolts and be readily caught.

Other fishes—the *silurus*, *malapterurus*, and so on—are likewise endowed with electric batteries for stunning and capturing their prey. The action of the organs is still a mystery, as, indeed, is the whole subject of animal electricity. Nobili and Matteucci discovered that feeble currents are generated by the excitation of the nerves and the contraction of the muscles in the human subject.

Electricity promises to become a valuable remedy, and currents—continuous, intermittent, or alternating—are applied to the body in nervous and muscular affections with good effect; but this should only be done under medical advice, and with proper apparatus.

In many cases of severe electric shock or lightning stroke, death is merely apparent, and

the person may be brought back to life by the method of artificial respiration and rhythmic traction of the tongue, as applied to the victims of drowning or dead faint.

A good lightning conductor should not have a higher electrical resistance than 10 ohms from the point to the ground, including the "earth" contact. Exceptionally good conductors have only about 5 ohms. A high resistance in the rod is due either to a flaw in the conductor or a bad earth connection, and in such a case the rod may be a source of danger instead of security, since the discharge is apt to find its way through some part of the building to the ground, rather than entirely by the rod. It is, therefore, important to test lightning conductors from time to time, and the magneto-electric tester of Siemens, which we illustrate in figures 98 and 99, is very serviceable

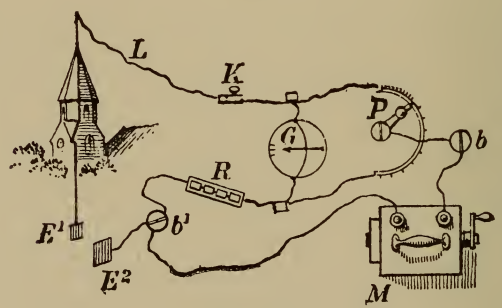



FIG. 98.

for the purpose, and requires no battery. The apparatus consists of a magneto-electric machine *M*, which generates the testing current by turning a handle, and a Wheatstone bridge. The

latter comprises a ring of German silver wire, forming two branches. A contact lever *P* moves over the ring, and is used as a battery key. A small galvanometer *G* shows the indications of

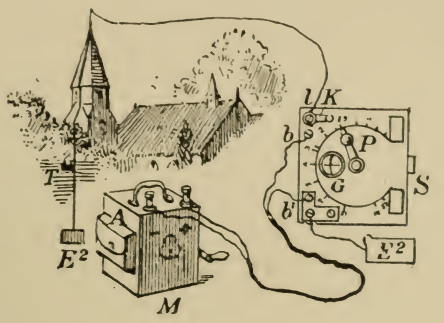



FIG. 99.

the testing current. A brass sliding piece *S* puts the galvanometer needle in and out of action. There are also several connecting terminals, *b b'*, *l*, &c., and a comparison resistance *R* (figure 98). A small key *K* is fixed to the terminal *l* (figure 99), and used to put the current on the lightning-rod, or take it off at will. A leather bag *A* at one side of the wooden case (figure 99) holds a double conductor leading wire, which is used for connecting the magneto-electric machine to the bridge. On turning the handle of *M* the current is generated, and on closing the key *K* it circulates from the terminals of the machine through the bridge and the lightning-rod joined with the latter. The needle of the galvanometer is deflected by it, until the resistance in the box *R* is adjusted to balance that in the rod. When this

is so, the galvanometer needle remains at rest. In this way the resistance of the rod is told, and any change in it noted. In order to effect the test, it is necessary to have two earth plates, $E^1$ and $E^2$, one ($E^1$) that of the rod, and the other ($E^2$) that for connecting to the testing apparatus by the terminal $b^1$ (figure 99). The whole instrument only weighs about 9 lbs. In order to test the "earth" alone, a copper wire should be soldered to the rod at a convenient height above the ground, and terminal screws fitted to it, as shown at $T$ (figure 99), so that instead of joining the whole rod in circuit with the apparatus, only that part from $T$ downwards is connected. The Hon. R. Abercrombie has recently drawn attention to the fact that there are three types of thunderstorm in Great Britain. The first, or squall thunderstorms, are squalls associated with thunder and lightning. They form on the sides of primary cyclones. The second, or commonest thunderstorms, are associated with secondary cy clones, and are rarely accompanied by squalls. The third, or line thunderstorms, take the form of narrow bands of rain and thunder—for example, 100 miles long by 5 to 10 miles broad. They cross the country rapidly, and nearly broadside on. These are usually preceded by a violent squall, like that which capsized the *Eurydice*.

The gloom of January, 1896, with its war and rumours of war, was, at all events, relieved by a single bright spot. Electricity has surprised the world with a new marvel, which confirms her title to be regarded as the most miraculous of all the sciences. Within the past twenty years she has given us the telephone of Bell, enabling London to speak with Paris, and Chicago with New

York; the microphone of Hughes, which makes the tread of a fly sound like the "tramp of an elephant," as Lord Kelvin has said; the phonograph of Edison, in which we can hear again the voices of the dead; the electric light which glows without air and under water, electric heat without fire, electric power without fuel, and a great deal more beside. To these triumphs we must now add a means of photographing unseen objects, such as the bony skeletons in the living body, and so revealing the invisible.

Whether it be that the press and general public are growing more enlightened in matters of science, or that Professor Röntgen's discovery appeals in a peculiar way to the popular imagination, it has certainly evoked a livelier and more sudden interest than either the telephone, microphone, or phonograph. I was present when Lord Kelvin first announced the invention of the telephone to a British audience, and showed the instrument itself, but the intelligence was received so apathetically that I suspect its importance was hardly realised. It fell to my own lot, a few years afterwards, to publish the first account of the phonograph in this country, and I remember that, between incredulity on the one hand, and perhaps lack of scientific interest on the other, a considerable time elapsed before the public at large were really impressed by the invention. Perhaps the uncanny and mysterious results of Röntgen's discovery, which seem to link it with the "black arts," have something to do with the quickness of its reception by all manner of people.

Like most, if not all, discoveries and inventions, it is the outcome of work already done by

other men. In the early days of electricity it was found that when an electric spark from a frictional machine was sent through a glass bulb from which the air had been sucked by an air pump, a cloudy light filled the bulb, which was therefore called an "electric egg." Hittorf and others improved on this effect by employing the spark from an induction coil and large tubes, highly exhausted of air, or containing a rare infusion of other gases, such as hydrogen. By this means beautiful glows of various colours, resembling the tender hues of the tropical sky, or the fleeting tints of the aurora borealis, were produced, and have become familiar to us in the well-known Geissler tubes.

Crookes, the celebrated English chemist, went still further, and by exhausting the bulbs with an improved Sprengel air-pump, obtained an extremely high vacuum, which gave remarkable effects (page 120). The diffused glow or cloudy light of the tube now shrank into a single stream, which joined the sparking points inserted through the ends of the tube as with a luminous thread. A magnet held near the tube bent the streamer from its course; and there was a dark space or gap in it near the negative point or cathode, from which proceeded invisible rays, having the property of impressing a photographic plate, and of rendering matter in general on which they impinged phosphorescent, and, in course of time, red-hot. Where they strike on the glass of the tube it is seen to glow with a green or bluish phosphorescence, and it will ultimately soften with heat.

These are the famous "cathode rays" of which we have recently heard so much. Apparently

they cannot be produced except in a very high vacuum, where the pressure of the air is about 1-100th millionth of an atmosphere, or that which it is some 90 or 100 miles above the earth. Mr. Crookes regards them as a stream of airy particles electrified by contact with the cathode or negative discharging point, and repelled from it in straight lines. The rarity of the air in the tube enables these particles to keep their line without being jostled by the other particles of air in the tube. A molecular bombardment from the cathode is, in his opinion, going on, and when the shots, that is to say, the molecules of air, strike the wall of the tube, or any other body within the tube, the shock gives rise to phosphorescence or fluorescence and to heat. This, in brief, is the celebrated hypothesis of "radiant matter," which has been supported in the United Kingdom by champions such as Lord Kelvin, Sir Gabriel Stokes, and Professor Fitzgerald, but questioned abroad by Goldstein, Jaumann, Wiedemann, Ebert, and others.

Lenard, a young Hungarian, pupil of the illustrious Heinrich Hertz, was the first to inflict a serious blow on the hypothesis, by showing that the cathode rays could exist outside the tube in air at ordinary pressure. Hertz had found that a thin foil of aluminium was penetrated by the rays, and Lenard made a tube having a "window" of aluminium, through which the rays darted into the open air. Their path could be traced by the bluish phosphorescence which they excited in the air, and he succeeded in getting them to penetrate a thin metal box and take a photograph inside it. But if the rays are a stream of radiant matter which can only exist in a high vacuum,

how can they survive in air at ordinary pressure? Lenard's experiments certainly favour the hypothesis of their being waves in the luminiferous ether.

Professor Röntgen, of Würzburg, profiting by Lenard's results, accidentally discovered that the rays coming from a Crookes tube, through the glass itself, could photograph the bones in the living hand, coins inside a purse, and other objects covered up or hid in the dark. Some bodies, such as flesh, paper, wood, ebonite, or vulcanised fibre, thin sheets of metal, and so on, are more or less transparent, and others, such as bones, carbon, quartz, thick plates of metal, are more or less opaque to the rays. The human hand, for example, consisting of flesh and bones, allows the rays to pass easily through the flesh, but not through the bones. Consequently, when it is interposed between the rays and a photographic plate, the skeleton inside is photographed on the plate. A lead pencil photographed in this way shows only the black lead, and a razor with a horn handle only the blade.

Thanks to the courtesy of Mr. A. A. Campbell Swinton, of the firm of Swinton & Stanton, the well-known electrical engineers, of Victoria Street, Westminster, a skilful experimentalist, who was the first to turn to the subject in England, I have witnessed the taking of these "shadow photographs," as they are called, somewhat erroneously, for "radiographs" or "cryptographs" would be a better word, and shall briefly describe his method. Röntgen employs an induction coil insulated in oil to excite the Crookes tube and yield the rays, but Mr. Swinton uses a "high frequency current," obtained from appara-

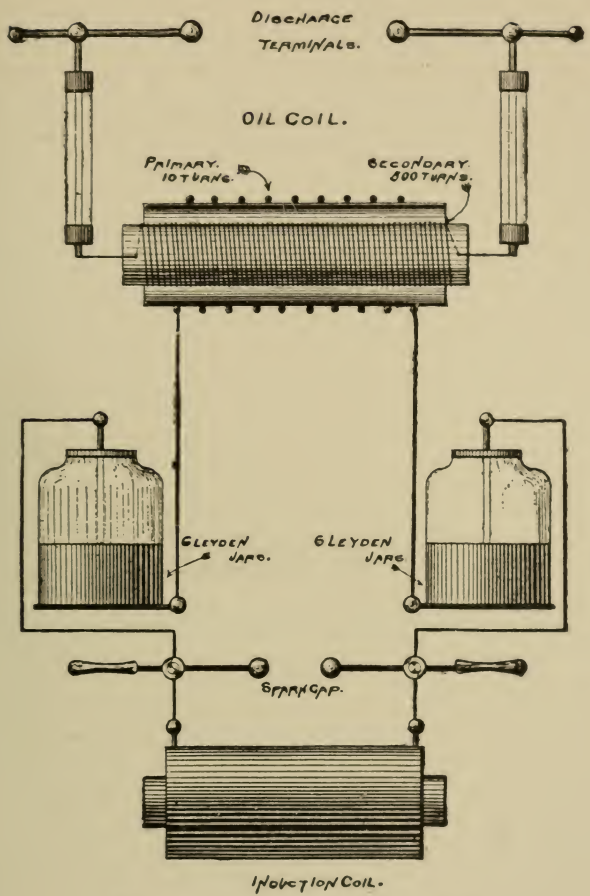



FIG. 100.—Photographing the Unseen.

tus similar to that of Tesla, and shown in figure 100, namely, a high frequency induction coil insulated by means of oil and excited by the continuous discharge of twelve half-gallon Leyden jars charged by an alternating current at a pressure of 20,000 volts produced by an ordinary large induction coil sparking across its high pressure terminals.

A vacuum bulb connected between the discharge terminals of the high frequency coil, as

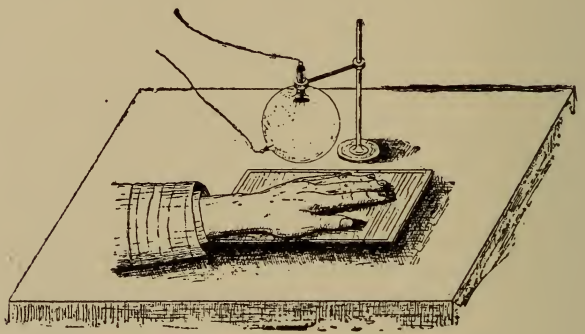


FIG. 101.—Photographing the Skeleton.

shown in figure 101, was illuminated with a pink glow, which streamed from the negative to the positive pole—that is to say, the cathode to the anode, and the glass became luminous with bluish phosphorescence and greenish fluorescence. Immediately under the bulb was placed my naked hand resting on a photographic slide containing a sensitive bromide plate covered with a plate of vulcanised fibre. An exposure of five or ten minutes is sufficient to give a good picture of the bones, as will be seen from the frontispiece.

The term "shadow" photograph requires a word of explanation. The bones do not appear as flat shadows, but rounded like solid bodies, as though the active rays passed through their substance. According to Röntgen, these "x" rays, as he calls them, are not true cathode rays, partly because they are not deflected by a magnet, but cathode rays transformed by the glass of the tube; and they are probably not ultra-violet rays, because they are not refracted by water or reflected from surfaces. He thinks they are the missing "longitudinal" rays of light whose existence has been conjectured by Lord Kelvin and others—that is to say, waves in which the ether sways to and fro along the direction of the ray, as in the case of sound vibrations, and not from side to side across it as in ordinary light.

Be this as it may, his discovery has opened up a new field of research and invention. It has been found that the immediate source of the rays is the fluorescence and phosphorescence of the glass, and they are more effective when the fluorescence is greenish-yellow or canary colour. Certain salts—for example, the sulphates of zinc and of calcium, barium platino-cyanide, tungstate of calcium, and the double sulphate of uranyle and potassium—are more active than glass, and even emit the rays after exposure to ordinary light, if not also in the dark. Salvioni of Perugia has invented a "cryptoscope," which enables us to see the hidden object without the aid of photography by allowing the rays to fall on a plate coated with one of these phosphorescent substances. Already the new method has been applied by doctors in examining malformations and diseases of the bones or internal organs, and

in localising and extracting bullets, needles, or other foreign matters in the body. There is little doubt that it will be very useful as an adjunct to hospitals, especially in warfare, and, if the apparatus can be reduced in size, it will be employed by ordinary practitioners. It has also been used to photograph the skeleton of a mummy, and to detect true from artificial gems. However, one cannot now easily predict its future value, and applications will be found out one after another as time goes on.

## CHAPTER X.

### THE WIRELESS TELEGRAPH.

Magnetic waves generated in the ether (see pp. 53–95) by an electric current flowing in a conductor are not the only waves which can be set up in it by aid of electricity. A merely stationary or "static" charge of electricity on a body, say a brass ball, can also disturb the ether; and if the strength of the charge is varied, ether oscillations or waves are excited. A simple way of producing these "electric waves" in the ether is to vary the strength of charge by drawing sparks from the charged body. Of course this can be done according to the Morse code; and as the waves after travelling through the ether with the speed of light are capable of influencing conductors at a distance, it is easy to see that signals can be sent in this way. The first to do so in a practical manner was Signor Marconi, a young Italian hitherto unknown to fame. In carrying

out his invention, Marconi made use of facts well known to theoretical electricians, one of whom, Dr. Oliver J. Lodge, had even sent signals with them in 1894; but it often happens in science as in literature that the recognised professors, the men who seem to have everything in their favour —knowledge, even talent—the men whom most people would expect to give us an original discovery or invention, are beaten by an outsider whom nobody heard of, who had neither learning, leisure, nor apparatus, but what he could pick up for himself.

Marconi produces his waves in the ether by electric sparks passing between four brass balls, a device of Professor Righi, following the classical experiments of Heinrich Hertz. The balls are electrified by connecting them to the well-known instrument called an induction coil, sometimes used by physicians to administer gentle shocks to invalids; and as the working of the coil is started and stopped by an ordinary telegraph key for interrupting the electric current, the sparking can be controlled according to the Morse code. In our diagram, which explains the apparatus, the four balls are seen at D, the inner and larger pair being partly immersed in vaseline oil, the outer and smaller pair being connected to the secondary or induced circuit of the induction coil C, which is represented by a wavy line. The primary or inducing circuit of the coil is connected to a battery B through a telegraph signalling key K, so that when this key is opened and closed by the telegraphist according to the Morse code, the induction coil is excited for a longer or shorter time by the current from the battery, in agreement with the longer and shorter signals of the

message. At the same time longer or shorter series of sparks corresponding to these signals pass across the gaps between the four balls, and give rise to longer or shorter series of etheric waves represented by the dotted line. So much for the "Transmitter." But how does Marconi transform these invisible waves into visible or audible signals at the distant place? He does this by virtue of a property discovered by Mr. S. A. Varley as far back as 1866, and investigated by Mr. E. Branly in 1889. They found that powder of metals, carbon, and other conductors, while offering a great resistance to the passage of an electric current when in a loose state, coheres together when electric waves act upon it, and opposes much less resistance to the electric current. It follows that if a Morse telegraph instrument at the distant place be connected in circuit with a battery and some loose metal dust, it can be adjusted to work when the etheric waves pass through the dust, and only then. In the diagram R is this Morse "Receiver" joined in circuit with a battery $B^1$; and a thin layer of nickel and silver dust, mixed with a trace of mercury, is placed between two cylindrical knobs or "electrodes" of silver fused into the glass tube *d*, which is exhausted of air like an electric glow lamp. Now, when the etheric waves proceeding from the transmitting station traverse the glass of the tube and act upon the metal dust, the current of the battery $B^1$ works the Morse receiver, and marks the signals in ink on a strip of travelling paper. Inasmuch as the dust tends to stick together after a wave passes through it, however, it requires to be shaken loose after each signal, and this is done by a small round hammer head seen on the right,

which gives a slight tap to the tube. The hammer is worked by a small electromagnet E, connected to the Morse instrument, and another battery *b* in what is called a "relay" circuit;

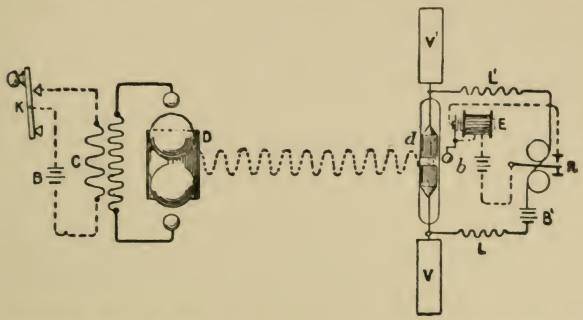



FIG. 102.—Marconi's Apparatus.

so that after the Morse instrument marks a signal, the hammer makes a tap on the tube. As this tap has a bell-like sound, the telegraphist can also read the signals of the message by his ear.

Two "self-induction bobbins," L $L^1$, a well-known device of electricians for opposing resistance to electric waves, are included in the circuit of the Morse instrument the better to confine the action of the waves to the powder in the tube. Further, the tube *d* is connected to two metal conductors V $V^1$, which may be compared to resonators in music. They can be adjusted or attuned to the electric waves as a string or pipe is to sonorous waves. In this way the receiver can be made to work only when electric waves of a certain rate are passing through the tube, just as a tuning-fork resounds to a certain note; it being

understood that the length of the waves can be regulated by adjusting the balls of the transmitter. As the etheric waves produced by the sparks, like ripples of water caused by dropping a stone into a pool, travel in all directions from the balls, a single transmitter can work a number of receivers at different stations, provided these are "tuned" by adjusting the conductors V $V^1$ to the length of the waves.

This indeed was the condition of affairs at the time when the young Italian transmitted messages from France to England in March, 1899, and it is a method that since has been found useful over limited distances. But to the inventor there seemed no reason why wireless telegraphy should be limited by any such distances. Accordingly he immediately developed his method and his apparatus, having in mind the transmission of signals over considerable intervals. The first question that arose was the effect of the curvature of the Earth and whether the waves follow the surface of the Earth or were propagated in straight lines, which would require the erection of aërial towers and wires of considerable height. Then there was the question of the amount of power involved and whether generators or other devices could be used to furnish waves of sufficient intensity to traverse considerable distances.

Little by little progress was made and in January, 1901, wireless communication was established between the Isle of Wight and Lizard in Cornwall, a distance of 186 miles with towers less than 300 feet in height, so that it was demonstrated that the curvature of the Earth did not seriously affect the transmission of the waves, as towers at least a mile high would have been required in case the

waves were so cut off. This was a source of considerable encouragement to Marconi, and his apparatus was further improved so that the resonance of the circuit and the variation of the capacity of the primary circuit of the oscillation transformer made for increased efficiency. The coherer was still retained and by the end of 1900 enough had been accomplished to warrant Marconi in arranging for trans-Atlantic experiments between Poldhu, Cornwall and the United States, stations being located on Cape Cod and in Newfoundland. The trans-Atlantic transmission of signals was quite a different matter from working over 100 miles or so in Great Britain. The single aërial wire was supplanted by a set of fifty almost vertical wires, supported at the top by a horizontal wire stretched between two masts 157½ feet high and 52½ feet apart, converging together at the lower end in the shape of a large fan. The capacity of the condenser was increased and instead of the battery a small generator was employed so that a spark 1½ inches in length would be discharged between spheres 3 inches in diameter.

At the end of the year 1901 temporary stations at Newfoundland were established and experiments were carried on with aërial wires raised in the air by means of kites. It was here realized that various refinements in the receiving apparatus were necessary, and instead of the coherer a telephone was inserted in the secondary circuit of the oscillation transformer, and with this device on February 12th the first signals to be transmitted across the Atlantic were heard. These early experiments were seriously affected by the fact that the antennæ or aërial wires were constantly varying in height with the movement of the kites, and it was found that a permanent arrangement of receiving wires, independent

of kites or balloons, was essential. Yet it was demonstrated at this time that the transmission of electric waves and their detection over distances of 2000 miles was distinctly possible.

A more systematic and thorough test occurred in February, 1902, when a receiving station was installed on the steamship *Philadelphia*, proceeding from Southampton to New York. The receiving aërial was rigged to the mainmast, the top of which was 197 feet above the level of the sea, and a syntonic receiver was employed, enabling the signals to be recorded on the tape of an ordinary Morse recorder. On this voyage readable messages were received from Poldhu up to a distance of 1551 miles, and test letters were received as far as 2099 miles. It was on this voyage that Marconi made the interesting discovery of the effect of sunlight on the propagation of electric waves over great distances. He found that the waves were absorbed during the daytime much more than at night and he eventually reached the conclusion that the ultraviolet light from the sun ionized the gaseous molecules of the air, and ionized air absorbs the energy of the electric waves, so that the fact was established that clear sunlight and blue skies, though transparent to light, serve as a fog to the powerful Hertzian waves of wireless telegraphy. For that reason the transmission of messages is carried on with greater facility on the shores of England and Newfoundland across the North Atlantic than in the clearer atmosphere of lower latitudes. But atmospheric conditions do not affect all forms of waves the same, and long waves with small amplitudes are far less subject to the effect of daylight than those of large amplitude and short wave length, and generators and circuits were arranged

to produce the former. But the difficulty did not prove insuperable, as Marconi found that increasing the energy of the transmitting station during the daytime would more than make up for the loss of range.

The experiments begun at Newfoundland were transferred to Nova Scotia, and at Glace Bay in 1902 was established a station from which messages were transmitted and experimental work carried on until its work was temporarily interrupted by fire in 1909. Here four wooden lattice towers, each 210 feet in height, were built at the corner of a square 200 feet on a side, and a conical arrangement of 400 copper wires supported on stays between the tops of the towers and connected in the middle at the generating station was built. Additional machinery was installed and at the same time a station at Cape Cod for commercial work was built. In December, 1902, regular communication was established between Glace Bay and Poldhu, but it was only satisfactory from Canada to England as the apparatus at the Poldhu station was less powerful and efficient than that installed in Canada. The transmission of a message from President Roosevelt to King Edward marked the practical beginning of trans-Atlantic wireless telegraphy. By this time a new device for the detection of messages was employed, as the coherer we have described even in its improved forms was found to possess its limitations of sensitiveness and did not respond satisfactorily to long distance signals. A magnetic detector was devised by Marconi while other inventors had contrived electrolytic, mercurial, thermal, and other forms of detector, used for the most part with a telephone receiver in order to detect minute variations in the current caused by the reception of the

electro-magnetic waves. With one of Marconi's magnetic detectors signals from Cape Cod were read at Poldhu.

In 1903 wireless telegraphy had reached such a development that the transmission of news messages was attempted in March and April of that year. But the service was suspended, owing to defects which manifested themselves in the apparatus, and in the meantime a new station in Ireland was erected. But there was no cessation of the practical experiments carried on, and in 1903 the Cunard steamship *Lucania* received, during her entire voyage across from New York to Liverpool, news transmitted direct from shore to shore. In the meantime intercommunication between ships had been developed and the use of wireless in naval operations was recognized as a necessity.

Various improvements from time to time were made in the aërial wires, and in 1905 a number of horizontal wires were connected to an aërial of the inverted cone type previously used. The directional aërial with the horizontal wires was tried at Glace Bay, and adopted for all the long distance stations, affording considerable strengthening of the received signals at Poldhu stations. Likewise improvements in the apparatus were effected at both trans-Atlantic stations, consisting of the adoption of air condensers composed of insulated metallic plate suspended in the air, which were found much better than the condensers where glass was previously used to separate the plates. For producing the energy employed for transmitting the signals a high tension continuous current dynamo is used. An oscillatory current of high potential is produced in a circuit which consists of rapidly rotating disks in connection with the dynamo and suitable condensers.

The production of electric oscillations can be accomplished in several ways and waves of the desired frequency and amplitude produced. Thus in 1903 it was found by Poulsen, elaborating on a principle first discovered by Duddell, that an oscillatory current may be derived from an electric arc maintained under certain conditions and that undamped high frequency waves so produced were suitable for wireless telegraphy. This discovery was of importance, as it was found that the waves so generated were undamped, that is, capable of proceeding to their destination without loss of amplitude. On this account they were especially suitable for wireless telephony where they were early applied, as it was found possible so to arrange a circuit with an ordinary microphone transmitter that the amplitude of the waves would be varied in harmony with the vibrations of the human voice. These waves so modulated could be received by some form of sensitive wave detector at a distant station and reproduced in the form of sound with an ordinary telephone receiver. With undamped waves from the arc and from special forms of generators wireless telephony over distances as great as 200 miles has been accomplished and over shorter distances, especially at sea and for sea to shore, communication has found considerable application. It is, however, an art that is just at the beginning of its usefulness, standing in much the same relation to wireless telegraphy that the ordinary telephone does to the familiar system employing metallic conductors.

On the spark and arc systems various methods of wireless telegraphy have been developed and improved so that Marconi no longer has any monopoly of methods or instruments. Various companies and

government officials have devised or modified systems so that to-day wireless is practically universal and is governed by an international convention to which leading nations of the world subscribe.

One of the recent features of wireless telegraphy of interest is the success of various directional devices. As we have seen, various schemes were tried by Marconi ranging from metallic reflectors used by Hertz in his early experiments with the electric waves to the more successful arrangement of aërial conductors. In Europe Bellini and Tosi have developed a method for obtaining directed aërial waves which promises to be of considerable utility, enabling them to be projected in a single direction just as a searchlight beam and thus restrict the number of points at which the signals could be intercepted and read. Likewise an arrangement was perfected which enabled a station to determine the direction in which the waves were being projected and consequently the bearing of another vessel or lighthouse or other station. The fundamental principle was the arrangement of the antennæ, two triangular systems being provided on the same mast, but in one the current is brought down in a perpendicular direction. The action depends upon the difference of the current in the two triangles.

Wireless telegraph apparatus is found installed in almost every seagoing passenger vessel of large size engaged in regular traffic, and as a means of safety as well as a convenience its usefulness has been demonstrated. Thus on the North Atlantic the largest liners are never out of touch with land on one side of the ocean or the other, and news is supplied for daily papers which are published on shipboard. Every ship in this part of the ocean equipped with the Marconi system, for example, is in communica-

tion on an average with four vessels supplied with instruments of the same system every twenty-four hours. In case of danger or disaster signals going out over the sea speedily can bring succour, as clearly was demonstrated in the case of the collision between the White Star steamship *Republic* and the steamship *Florida* on January 26, 1909. Here wireless danger messages were sent out as long as the *Republic* was afloat and its wireless apparatus working. These brought aid from various steamers in the vicinity and the passengers were speedily transferred from the sinking *Republic*. On April 15, 1912, the White Star liner *Titanic*, the largest ship afloat, sank off Newfoundland, after colliding with an iceberg. Wireless S O S calls for help brought several steamships to the scene, and 703 persons from a total of 2,206, were rescued. On October 9, 1913, the Uranium liner *Volturno* caught fire in mid-ocean, and her wireless calls brought ten steamships to her aid, which, despite a heavy sea, rescued 532 persons from a total of 657. Again, on November 14, 1913, the Spanish steamship *Balmes* caught fire off Bermuda, and at her wireless call the Cunard liner *Pannonia* saved all of her passengers—103. The *Titanic* horror led the principal maritime nations to take immediate steps to perfect their wireless systems, and the installation of apparatus and operators soon became a prime requisite of the equipment of the world's shipping.

Wireless telegraphy has been developed to great efficiency in all the leading navies, and powerful plants are installed on all warships. The United States, Great Britain, and Germany, most noticeably, have established shore stations, by which they can "talk all around the world" from any ship or station. In operation secrecy is most important. For

in the navy practically all important messages are sent in code or cipher under all conditions while in commercial work the tapping of land wires or the stealing of messages while illegal is physically possible for the evil disposed yet has never proved in practice a serious evil. The problem of interference, however, seems to have been fairly solved by the large systems though the activity of amateurs is often a serious disturbance for government and other stations.

Despite the progress of wireless telegraphy it has not yet supplanted the submarine cable and the land wire, and in conservative opinion it will be many years before it will do so. In fact, since Marconi's work there has been no diminution in the number or amount of cables laid and the business handled, nor is there prospect of such for years to come. While the cable has answered admirably for telegraphic purposes yet for telephony over considerable distances it has failed entirely so that wireless telephony over oceans starts with a more than favorable outlook. But wireless telegraphy to a large extent has made its own field and here its work has been greatly successful. Thus when Peary's message announcing his discovery of the North Pole came out of the Frozen North, it was by way of the wireless station on the distant Labrador coast that it reached an anxious and interested civilization. It is this same wireless that watches the progress of the fishing fleets at stations where commercial considerations would render impossible the maintenance of a submarine cable. It is the wireless telegraph that maintains communication in the interior of Alaska and between islands in the Pacific and elsewhere where conditions of development do not permit of the more expensive

installation of submarine cable or climatic or other conditions render impossible overland lines. At sea its advantages are obvious. Everywhere the ether responds to the impulses of the crackling sparks, and even from the airship we soon may expect wireless messages as the few untrodden regions of our globe are explored.

## CHAPTER XI.

### ELECTRO-CHEMISTRY AND ELECTRO-METALLURGY.

In no department of the application of electricity to practical work has there been a greater development than in electro-metallurgy and electro-chemistry. To-day there are vast industries depending upon electrical processes and the developments of a quarter of a century have been truly remarkable. Already more than one-half of the copper used in the arts is derived by electrolytic refining. The production of aluminum depends entirely on electricity, the electric furnace as a possible rival to the blast furnace for the production of iron and steel is being seriously considered, and many other metallurgical processes are being undertaken on a large scale. We have seen in our chapter on Electrolysis how a metal may be deposited from a solution of its salt and how this process could be used for deriving a pure metal or for plating or coating with the desired metal the surface of another metal or one covered with graphite. In the following pages it is intended to take up some of the more notable accomplishments in this field achieved by electricity, which have been developed to a state of commercial importance.

The electric arc not only supplies light, but heat of great intensity which the electrical engineer as well as the pure scientist has found so valuable for many practical operations. It is of course obvious that for most chemical operations, and especially in the field of metallurgy, heat is required for the separation of combinations of various elements, for their purification, as well as for the combination with other elements into alloys or compounds of direct utility. The usual method of generating heat is by the combustion of some fuel, such as coal, coke, gas or oil, and this has been utilized for hundreds of years in smelting metals and ores and in refining the material from a crude state. Now it may happen that a nation or region may be rich in metalliferous ores, but possess few, if any, coal deposits. Accordingly the ore must be mined and transported considerable distances for treatment and the advantages of manufacturing industries are lost to the neighborhood of its original production. But if water power is available, as it is in many mountainous countries where various ores are found, then this power can be transformed into electricity which is available as power not only in various manufacturing operations, but for primary metallurgical work in smelting the ores and obtaining the metal therefrom. A striking instance of this is the kingdom of Sweden, which contains but little coal, yet is rich in minerals and in water power, so that its waterfalls have been picturesquely alluded to as the country's "white coal." Likewise, at Niagara Falls a portion of the vast water power developed there has been used in the manufacture of aluminum, calcium carbide, carborundum, and other materials, while at other points in the United States and Canada, not to mention Europe, large indus-

tries where electricity is used for metallurgical or chemical work are carried on and the erection of new plants is contemplated.

The application of electricity to metallurgical and chemical work has been, in nearly all cases, the result of scientific research, and elaborate experimental laboratories are maintained by the various corporations interested in the present or future use of electrical processes. It is recognized by many of the older workers in this field that electrical developments are bound to come in the near future, and while they have not installed such appliances in their works yet they are keeping close watch of present developments, and in many cases experimental investigation and research is being carried on where electrical methods have not yet been introduced generally into the plant.

Prior to 1886 the refining of copper was the only electro-metallurgical industry and at that time it was carried on on a very limited scale. To-day the production of electrolytic copper as an industry is second in importance only to the actual production of that metal. From the small refinery started by James Elkington at Pembury in South Wales, a vast industry has developed in which there has been a change in the size of operations and in the details of methods rather than in the fundamental process. For a solution of copper sulphate is employed as the electrolyte, blocks of raw copper as the anodes, and thin sheets of pure copper as the cathodes. The passage of the electric current, as we have seen on page 79, in the chapter on Electrolysis, is able to decompose the copper in the electrolyte and to precipitate chemically pure copper on the cathode, the copper of the solution being replenished from the raw material used as the anode by which the cur-

rent is passed into the bath. At this Welsh factory 250 tons yearly were produced, and small earthenware pots sufficed for the electrolyte. Thirty years later one American factory alone was able to produce at least 350 tons of electrolytic copper in twenty-four hours, and over 400,000 tons is the aggregate output of the refineries of the world, which is about 53 per cent. of the total raw copper production. Of this amount 85 per cent. comes from American refineries, whose output has more than doubled since 1900.

The chief reason for this increased output of electrolytic copper has been the great demand for its use in the electrical industries where not only a vast amount is consumed, but where copper of high purity, to give the maximum conductivity required by the electrical engineer, is demanded. When it is realized that every dynamo is wound with copper wire and that the same material is used for the trolley wire and for the distribution wires in electric lighting, it will be apparent how the demand for copper has increased in the last quarter of a century. Electrolytic methods not only supply a purer article and are economical to operate, especially if there is water power in the vicinity, but the copper ores contain varying amounts of silver and gold which can be recovered from the slimes obtained in the electrolytic process. Wherever possible machinery has been substituted for hand labor, the raw copper anodes have been cast, and the charging and discharging of the vats is carried on by the most modern mechanical methods in which efficiency and economy are secured. On the chemical side of the process attempts have been made to improve the electrolyte, notably by the addition of a small amount of hydrochloric acid to prevent the loss of

silver in the slimes, and this part of the work is watched with quite as much care as the other stages. Electric furnaces have also been constructed for smelting copper ores, but these have not found wide application, and the problem is one of the future. For the most part the copper electrically refined is produced in an ordinary smelter. The mints of the United States are now all equipped with electrolytic refining plants to produce the pure metal needed for coinage and they have proved most satisfactory and economical.

As the electrolytic production of copper is an industry of great present importance, so the production of iron and steel by electricity promises to be of the greatest future importance. Electric furnaces for making steel are now maintained, and the industry has passed beyond an experimental condition. But it has not reached the point where it is competing with the Bessemer or the open hearth process of the manufacture of steel, while for the smelting of iron ores the electric furnace has not yet been found practical from an economic standpoint. Before 1880 Sir William Siemens showed that an electric arc could be used to melt iron or steel in a crucible, and he patented an electric crucible furnace which was the first attempt to use electricity in iron and steel manufacture. He stated that the process would not be too costly and that it had a great future before it. This was an application of the intense heat of the arc, which supplies a higher temperature than any source known except that of the sun. This heat is used to melt the metal, in which condition various impurities can be removed and necessary ingredients added. Siemens' furnace did not find extensive application, largely on account of the great metallurgical developments then taking

place in the iron industry and the thorough knowledge of metallurgical processes as carried on, possessed by metallurgical engineers. But the idea by no means languished, and in 1899 Paul Heroult and other electro-metallurgists were active in developing a practical electric furnace for iron and steel work. The Swedish engineer, F. A. Kjellin, was also active and as the result of the efforts of these and other workers, by 1909 electric furnaces were employed, not only in the manufacture of special steels whose composition and making were attended with special care, but for rails and structural material. There were reported to be between thirty and forty electric steel plants in various countries, and the outlook for the future was distinctly bright. The application of electro-metallurgy at this time was confined to the manufacture of steel, as the smelting of iron had not emerged from the experimental stage of its development, though extensive trials on a large scale of various furnaces have been undertaken in Europe and by the Canadian government at Sault Ste. Marie, where the Heroult furnace, soon to be described, was employed. Electro-metallurgy of steel, as in all utilization of electrical power, depends upon obtaining electricity at a reasonable cost, and then utilizing the heat of the arc or of the current in the most practical and economical form.

One of the pioneer furnaces for this purpose which has seen considerable development and practical application is the Heroult furnace, which is a tilting furnace of the crucible type, whose operation depends upon both the heat of the arc and on the heat produced by the resistance of the molten material. In the Heroult process the impurities of the molten iron are washed out by treatment with suitable slags. The furnace consists of a crucible

in the form of a closed shallow iron tank, thickly lined with dolomite and magnazite brick, with a hearth of crushed dolomite. The electric current enters the crucible through two massive electrodes of solid carbon, 70 inches in length and 14 inches in diameter, so mounted that they can be moved either vertically or horizontally by the electrician in charge. These electrodes are water-jacketed to reduce the rate of consumption. The furnace contains an inlet for an air blast and openings in its covering for charging the material and for the escape of the gases. The actual process of steel-making consists of charging the crucible with steel scrap, pig iron, iron ore, and lime of the proper quality and in the right proportions, placing this material on the hearth of the furnace. Combined arc and resistance heating is applied to raise the charge to the melting point. The current is of 120 volts or the same as that used in an ordinary incandescent lighting circuit, but is alternating and of 4,000 amperes. This is for a three-ton furnace. As the material melts the lime and silicates form a slag which fuses rapidly and covers the iron and steel in the crucible, so that the molten bath is protected from the action of the gases which are liberated and the oxygen in the atmosphere. The next step in the process is to lower the electrodes until they just touch beneath the surface of the molten slag so that subsequent heating is due not to the effect of the arc but to the resistance which the bath offers to the passage of the current.

Air from an air blast is introduced into the crucible to oxidize the impurities of the metal, particularly the sulphur and the phosphorus which are carried into the slag and this is removed by the tilting of the furnace. Fresh quantities of lime,

etc., are added, and the operation is repeated until a comparatively pure metal remains, when an alloy high in carbon is added and whatever other constituents are desired for the finished steel. The charge is then tipped into the casting ladle and the part of the electric furnace is finished. For three tons of steel eight to ten hours are required in the Heroult crucible furnace.

Furnaces of an altogether different type are those employing an alternating current, such as the Kjellin and Röchling furnaces, where the metal to be heated really forms the secondary circuit of a large and novel form of transformer which in principle is analogous to the familiar transformer seen to step down the potential of alternating current as for house lighting. For such a transformer the primary coil is formed of heavy wire and the secondary circuit is the molten metal which is contained in an annular channel. The current obtained in the metal is of considerable intensity, but at lower potential than that in the primary coil, and roughly is equal to that of the primary multiplied by the number of turns in the coil. The condition is similar to that in the ordinary induction coil where the current from a battery at low potential flows around a coil of a few turns and is surrounded by a second coil with a large number of turns of fine wire in which current of small intensity but of high potential is generated. In the induction furnace the reverse takes place and the current flowing in the metal derived from that of the heavy coil in the primary is of great intensity. For this type of furnace molten metal is required and the furnace is never entirely emptied, so that its process is continuous. The temperature attained is not as high as in the arc furnace, so that

the raw materials used have to be of a high degree of purity, and this has proved a restriction of the field of usefulness of this type of furnace in many cases. It, however, has been improved recently and two rings of molten metal employed instead of one so that a wide centre trough is obtained in which the metal is subjected to ordinary resistance heat by direct or alternating currents. This furnace permits of various metallurgical operations and the elimination of impurities as in the Heroult type.

A third type of furnace that is meeting with some extensive use is the Giroud, which, like the Heroult furnace, is based on the arc and resistance in principle, but in its construction has a number of different features. As the current passes horizontally from the upper electrodes through the slag and molten metal in the furnace chamber to the base electrodes of the furnace, it permits of the easy regulation of the arcs and the use of lower electromotive force, while there is only one arc in the path of the current instead of two as in the Heroult type.

Sufficient quantities of steel have been made in electric furnaces to permit of the determination of the quality of the product as well as the economy of the process. It has been found in Germany that rail steel made in the induction furnace has a much higher bending and breaking limit than ordinary Bessemer or Thomas rail steel, and in Germany in 1908 rails so made commanded a considerably higher price per ton than those of ordinary rail steel. After trial orders had proved satisfactory, in 1908 5,000 tons of rails were ordered for the Italian and Swiss governments at a German works, where furnaces of eight tons capacity had been installed.

In the United States only a few electric steel furnaces are in operation, and these, for the most part, for purposes of demonstration and experiment. But in Europe the industry is well established, and while at present small, is constantly growing and possesses an assured future.

In addition to the manufacture of steel, the application of the electric furnace for producing what are known as ferro-alloys, or alloys of iron, silicon, chromium, manganese, tungsten and vanadium, is now a large and important industry. Special steels have their uses in different mechanical applications and the advantage of alloying them with the rarer metals has been demonstrated for several important purposes, as for example, the use of chrome steel for armor plate, and steel containing vanadium for parts of motor cars. These industries for the most part contain electric arc furnaces and have, as their object, the manufacture of ferro-alloys, which are introduced into the steel, it having been found advantageous to use the rare metals in this form rather than in their crude state.

There is one electro-metallurgical process that has made possible the production in commercial form and for ordinary use of a metal that once was little more than a chemical curiosity. In 1885 there were produced 3.12 tons of aluminum, and its value was roughly estimated at about $12 a pound. By 1908 America alone produced over 9,000 tons valued at over $500,000,000, while European manufacturers were also large producers. In 1888 the electrolytic manufacture of aluminum was commenced in America and in the following year it was begun in Switzerland. Aluminum is formed by the electrolysis of the aluminum oxide in a fused bath of cryolite and fluorspar. The aluminum may be

obtained in the form of bauxite, and is produced in large rectangular iron pots with a thick carbon lining. The pot itself is the cathode, while large graphite rods suspended in the bath serve as the anodes. After the arc is formed and the heat of the bath rises to a sufficient degree the material is decomposed and the metal is separated out so that it can be removed by ladling or with a siphon. The application of heat to obtain this metal previous to the invention of the electric furnace could only be considered a laboratory problem and the expense involved did not permit of commercial application. Now, however, aluminum is universally available and with the expiration of certain patents, the material has sold as low as 25 cents a pound.

Electrolytic methods serve also for the refining of nickel and for the production of lead, and as in other fields of metallurgy, these processes are attracting the attention of chemists and of engineers. While tin as yet has not yielded to electrolytic or electro-thermal methods with any success, the removal of tin from tin scraps and cuttings has been carried on with considerable success. With zinc the electrolytic and electro-thermal processes have not been able yet to compete with the older metallurgical method of distillation, but an important industry is electro-galvanizing, where a solution of zinc sulphate is deposited on iron and gives a protective coating. Experimental methods with the use of electricity in extracting zinc from its ores are being tested at various European plants, but the matter has not yet reached a commercial scale.

One of the earliest notable uses of the electric furnace in a large electro-chemical industry was for the production of carborundum, a carbide of silicon, which is remarkably useful as an abrasive, being

available in the manufacture of grinding stones and other like purposes to replace emery and corundum. It is produced by the use of a simple electric furnace of the resistance type, where coke, sand, and sawdust are heated to a temperature of between 2000° and 3000° C. The chemical reaction involves the production of carbon monoxide, and gives a carbide of silicon, a crystalline solid which has the excellent abrasive properties mentioned. The manufacture was first started by its inventor, E. G. Acheson, about 1891 on a small scale, and in the following year 1,000 pounds of the material were produced at the Niagara Falls works. Within fifteen years its output had increased to well over six million pounds.

The electric furnaces at Niagara Falls have supplied many interesting electro-chemical processes. After making a carbide in the electric furnace it was found possible to decompose it by further increasing the heat to a point where the second element is volatilized and the pure carbon in the form of artificial graphite remains. In more recent work the carbide containing the silicon has been done away with and ordinary anthracite coal used as a charge from which the pure graphite is obtained. This graphite has been found especially useful in electrical work as for electrodes, while a more recent process enables a soft variety of graphite to be obtained which becomes a competitor of the natural material.

One of the most interesting of the many electro-chemical processes is the heating of lime and coke in the electric furnace so as to obtain a product in the form of calcium carbide, which, on solution in water, forms acetylene gas, a useful and valuable illuminant. This process dates from 1893 when

T. L. Willson in the United States first started its manufacture on a large scale, and the great electro-chemist, Henri Moissin, about the same time independently invented a similar process as a result of his notable work with the electric furnace. The process involves merely a transformation at a high temperature, a portion of the carbon in the form of coke, uniting with pulverized lime to give the calcium carbide or $C_aC_2$. Now this material, when water is added to it, decomposes, and acetylene or $C_2H_2$ is formed, which is a gas of high illuminating value as the carbon separates and glows brightly after being heated to incandescence in the flame.

The electric furnace at Niagara Falls has been able to produce still another combination in the form of siloxicon by heating carbon and silicon to a temperature slightly below that required to produce carborundum. This product is a highly refractory material and is valuable for the manufacture of crucibles, muffles, bricks, etc., for work where extreme temperatures are employed. The electric furnace enables various elements to be isolated, such as silicon, sodium, and phosphorus, and when obtained in their pure state they find wide application.

The most important electro-chemical work of the future is to devise some means of obtaining nitrogen from the air. It is stated by scientists that the nitrogen of the soil is being exhausted and that at some future time the Earth may not be able to bear crops sufficient for the sustenance of man, unless some artificial means be found to replenish the nitrogen. Unlimited supplies of nitrogen exist in the air, but to fix it with other materials in such form that it will be useful as a fertilizer has been one of the problems to which the electro-chemists have recently devoted much attention. By the use

of the electric arc and passing air through a furnace, various substances have been tried to take up the nitrogen of the air. Thus when calcium carbide is heated and brought into contact with nitrogen one atom of carbon is given up and two atoms of nitrogen take its place, resulting in the production of cyanamide.

Other important electro-chemical processes are involved in the electrolysis of the various alkaline salts to obtain metallic sodium and such products as chlorates. Thus by the electrolysis of sodium chloride metallic sodium and chlorine is obtained. From the metallic sodium solid caustic soda is then derived by a secondary reaction, while the chlorine is combined with lime to form chloride of lime or bleaching powder. In some processes the electrolysis affords directly an alkaline hypochlorite or a chlorate, the former being of wide commercial use as a bleaching agent in textile works and in the paper industry. The same process employed in the electrolysis of sodium salts is used in the case of magnesium and calcium.

Electrolysis is also made use of in the manufacture of chloroform and iodoform, as the chlorine or iodine which is produced in the electrolytic cell is allowed to act upon the alcohol or acetone under such conditions that chloroform or iodoform is produced.

Electro-chemistry plays an important part in many other industries whose omission from our description must not be considered as indicating any lack of their importance. New processes constantly are being discovered which may range all the way from the production of artificial gems to the wholesale production of the most common chemicals used in the arts. In many branches of

chemical industry manufacturing processes have been completely changed, and from the research laboratories, which all large progressive manufacturers now maintain, as well as from workers in universities and scientific schools, new methods and discoveries are constantly forthcoming.

## CHAPTER XII.

### ELECTRIC RAILWAYS.

THE electric railway of Dr. Werner von Siemens constructed at Berlin in 1879 was the forerunner of a number of systems which have had the effect of changing materially the problems of transportation in all parts of the world. The electric railway not only was found suitable as a substitute for the tramway with its horse-drawn car, but far more economical than the cable cars, which were installed to meet the transportation problems of large cities with heavy traffic, or, as in the case of certain cities on the Pacific slope, where heavy grades made transportation a serious problem. Furthermore, the electric railway was found serviceable for rural lines where small steam engines or "dummies" were operated with limited success, and then only under exceptional conditions. As a result, practically every country of the world where the density of population and the state of civilization has warranted, is traversed by a network of electric railways, securing the most complete intercommunication between the various localities and handling local transportation in a manner impossible for a railway line employing steam locomotives.

The great advance in electric transportation, aside from its meeting an economic need, has been due to the development of systems of generating and transmitting power economically over long distances. If water power is available, turbines and electric generators can be installed and power produced and transmitted over long distances, as, for example, from Niagara Falls to Buffalo, or even to much greater distances as in the case of power plants on the Pacific coast where mountain streams and lakes are employed for this purpose with considerable efficiency. A high tension alternating current thus can be transmitted over considerable distances and then transformed into direct current which flows along the trolley wires and is utilized in the motors. This transformation is usually accomplished by means of a rotary converter, that is, an alternating current motor which carries with it the essential elements of a direct current dynamo and receiving the alternating current of high potential turns it out in the form of direct current at a lower and standard potential. The alternating current at high potential can be transmitted over long distances with a minimum of loss, while the direct current at lower potential is more suitable for the motor and can be used with greater advantage, yet its potential or pressure decreases rapidly over long lengths of line, so that it is more economical to use sub-stations to convert the alternating current from the power plant. It must not be inferred, however, that all electric railways employ direct current machinery. In Europe alternating current has been used with great success and also in the United States where a number of lines have been equipped with this form of power. But the greater number of installations employ the direct current at about

500–600 volts and this is now the usual practice. Whether it will continue so in the future or not is perhaps an open question.

The electric car, as we have seen, employs a motor which is geared to the axle of the driving trucks, and the current is derived from the trolley wire by the familiar pole and wheel and after flowing through the controller to the motor returns by the rail. The speed of the car is regulated by the amount of current which the motorman allows to pass through the motor and the circuits through which it flows in order to produce different effects in the magnetic attraction of the magnet and the armature. In the ordinary electric car for urban or suburban uses there has been a constant increase in the power of the motor and size of the cars, as it has been found that even large cars can be handled with the required facility necessary in crowded streets and that they are correspondingly more economical to maintain and operate.

The success of electric traction in large cities had been demonstrated but a few years when it was appreciated that the overhead wires of the trolley were unsightly and dangerous, especially in the case of fire or the breaking of the wires or supports. Accordingly a system was developed where the current was obtained from conductors laid in a conduit on insulated supports through a slot in the centre of the track between the rails. A plow suspended from the bottom of the car was in contact with the conductors which were steel rails mounted on insulated supports, and through them the current passed by suitable conductors to the controller and motors. This system found an immediate vogue in American cities, and though more costly to install than the overhead trolley, was far more satisfactory

in its results and appearance. In certain cities, Washington, D. C., for example, the conduit is used in the built-up portion of the town and when the suburbs are reached the plow is removed and the motors are connected with the trolley wire by the usual pole and wheel.

Perhaps the most important feature of the electric railway in the United States has been the development and increase of its efficiency. Wherever possible traffic conditions warranted, it was comparatively easy to secure the right of way along country highways with little, if any, expense, and the construction of track and poles for such work was not a particularly heavy outlay. It was found, as we have seen, that the current could be transmitted over considerable distances so that the opportunity was afforded to supply transportation between two towns at some small distance where the local business at the time of the construction of the road would not warrant the outlay. This led to the systems of interurban lines, small at first, but as their success was demonstrated, gradually extending and uniting so that not only two important towns were connected, but eventually a large territory was supplied with adequate transportation facilities and even mail, express, and light freight could be handled.

Again the success of such enterprises made it feasible for the electric railways to forsake the public highway and to secure a right of way of their own, and gradually to develop express and through service, often in direct competition with the local service of the steam railways in the same territory. Here larger cars were required and power stations of the most modern and efficient type in order to secure proper economy of operation. The general

character of machinery, both generators and motors, was preserved even for these long distance lines, and their operation became simply an engineering problem to secure the maximum efficiency with a minimum expenditure.

With the success of electric railways in cities and for suburban and interurban service naturally arose the question, why electric power whose availability and economy had been shown in so many circumstances could not be used for the great trunk lines where steam locomotives have been developed and employed for so many years? The question is not entirely one of engineering unless as part of the engineering problem we consider the various economic elements that enter into the question, and their investigation is the important task of the twentieth century engineer. For he must answer the question not only is a method possible mechanically, but is it profitable from a practical and economic standpoint? And it is here that the question of the electrification of trunk lines now rests. The steam locomotive has been developed to a point perhaps of almost maximum efficiency where the greatest speed and power have been secured that are possible on machines limited by the standard gauge of the track, 4 ft. 8½ in., and the curves which present railway lines and conditions of construction demand. Now, withal, the steam locomotive mechanically considered is inefficient, as it must take with it a large weight of fuel and water which must be transformed into steam under fixed conditions. If for example, we have one train a day working over a certain line, there would be no question of the economy of a steam locomotive, but with a number, we are simply maintaining isolated units for the production of power which could be developed to far greater ad-

vantage in a central plant. Just as the factory is more economical than a number of workers engaged at their homes, and the large establishment of the trust still more economical in production than a number of factories, so the central power station producing electricity which can be transmitted along a line and used as required is obviously more advantageous than separate units producing power on the spot with various losses inherent in small machines.

But even if the central station is theoretically superior and more economical it does not imply that it is either good policy or economy to electrify at once all the trunk lines of a country such as the United States and to send to the scrap heap thousands of good locomotives at the sacrifice of millions of dollars and the outlay of millions more for electrical equipment. In other words, unless the financial returns will warrant it, there is no good and positive reason for the electrification of our great trans-continental lines and even shorter railroads. That is the situation to-day, but to-morrow is another question, and the far-seeing railroad man must be ready with his answer and with his preparations. To-day terminal services in large cities can better be performed by electricity, and not only is there economy in their operation, but the absence of dirt, smoke and noise is in accord with public sentiment if not positively demanded by statute or ordinance. Suburban service can be worked much more economically and effectively by trains of motor cars, and time table and schedule are not limited by the number of available locomotives on a line so equipped. On mountain grades, where auxiliary power or engines of extreme capacity are required, electricity generated by water power from melting

snow or mountain lakes or streams in the vicinity may be availed of. Under such conditions powerful motors can be used on mountain divisions, not only with economy, but with increased comfort to passengers, especially where there are long tunnels. All this and more the railway man of to-day realizes, and electrification to this extent has been accomplished or is in course of construction. For each one of the services mentioned typical installations can be given as examples, and to accomplish the various ends, there is not only one system but several systems of electrical working, which have been devised by electrical engineers to meet the difficulties.

To summarize then, electric working of a trunk line results in increased economy over steam locomotives by concentration of the power and especially by the use of water power where possible. Thus economy is secured to the greatest extent by a complete electrical service and not by a mixed service of electric and steam locomotives. Electrification gives an increase in capacity both in the haulage by a locomotive, an electric locomotive being capable of more work than a steam locomotive, and in schedule and rate of speed, as motor car trains and electric terminal facilities make possible augmented traffic, and an increased use of dead parts of the system such as track and roadbed. There is a great gain in time of acceleration and for stopping, and for the Boston terminal it was estimated that with electricity 50 per cent. more traffic could be handled, as the headway could be reduced from three to two minutes. The modern tendency of electrification deals either with special conditions or where the traffic is comparatively dense. From such a beginning it is inevitable that

electric working should be extended and that is the tendency in all modern installations, as for example, at the New York terminal of the New York Central and Hudson River Railroad where the electric zone, first installed within little more than station limits, is gradually being extended. As examples of density of traffic suitable for electrification, yet at the same time possessing problems of their own, are the great terminals such as the Grand Central Station of the New York Central and Hudson River Railroad in New York City, the new Pennsylvania Station in the same city, and that of the Illinois Central Station in the city of Chicago. Not only is there density here but the varied character of the service rendered, such as express, local, suburban, and freight, involves the prompt and efficient handling of trains and cars. Now, with suburban trains made up of motor cars, a certain number of locomotives otherwise employed are released; for these cars can be operated or shifted by their own power. Such terminal stations are often combined with tunnel sections, as in the case of the great Pennsylvania terminal, where the tunnel begins at Bergen, New Jersey, and extends under the Hudson River, beneath Manhattan Island and under the East River to Long Island City. It is here that electric working is essential for the comfort of passengers as well as for efficient operation. But there are tunnel sections not connected with such vast terminals, as in the case of the St. Clair tunnel under the Detroit River.

While the field and future direction of electrification is fairly well outlined and its future is assured, yet this future will be one of steady progress rather than one of sudden upheaval for the economic reasons before stated. To-day there are no final

standards either of systems or of motors and the field is open for the final evolution of the most efficient methods. Notwithstanding the extraordinary progress that has been made many further developments are not only possible now but will be demanded with the progress of the art.

The great problem of the electric railway is the transmission of energy, and while power may be economically generated at the central station, yet, as Mr. Frank J. Sprague, one of the pioneers and foremost workers in the electrical engineering of railways has so aptly said, it is still at that central station and it will suffer a certain diminution in being carried to the point of utilization as well as in being transformed into power to move locomotives, so that these two considerations lie at the bottom of the electric railway and on them depend the choice of the system and the design and construction of the motor. The two fundamental systems for electric railways, as in other power problems, are the direct current and the alternating current. In the former we have the familiar trolley wire, fed perhaps by auxiliary conductors carried on the supporting poles or the underground trolley in the conduit, or the third rail laid at the side of the track. All of these have become standard practice and are operated at the usual voltage of from 500 to 600 volts. The current on lines of any considerable length is alternating current, supplied from large central generating stations and transformed to direct as occasion may demand at suitable sub-stations. Recently there has been a tendency to employ high voltage direct current systems where the advantages of the use of direct current motors are combined with the economies of high voltage transmission, chief of which are the avoiding of power losses in transmis-

sion and the economy in the first cost of copper. These high voltage direct current lines were first used in Europe, and during the year 1907 experimental lines on the Vienna railway were tested. In Germany and Switzerland tests were made of direct current system of 2,000 and 3,000 volts and in 1908 there was completed the first section of a 1,200-volt direct current line between Indianapolis and Louisville, which marked the first use of high tension direct current in the United States, and this was followed by other successful installations.

With alternating current there can be used the various forms of single phase or polyphase current familiar in power work, but the latter is now preferred, and in Europe and in the United States in the latter part of 1908 the number of single phase lines was estimated at 27 and 28 respectively, with a total mileage of 782 and 967 miles. A trolley wire or suspended conductor is used. To employ a single phase current, motors of either the repulsion type or of the series type are used and are of heavier weight than the direct current motors, as they must combine the functions of a transformer and a motor. It is for this reason that we often see two electric locomotives at the head of a single train on lines where the single phase system is employed, while on neighboring lines using direct current, one locomotive of hardly larger size suffices. With the polyphase current a motor with a rotating field is used, and they have considerable efficiency as regards weight when compared with the single phase and with the direct current motor. The polyphase motor, however, is open to the objection that it does not lend itself to regulations as well as the direct current form, and with ingenious devices involving the arrangement of the magnetic field and

the combination of motors, various running speeds can be had. The usual voltage for these motors is 3,000 volts, but in the polyphase plant designed for the Cascade Tunnel 6,000 volts are to be used. They possess many advantages, especially their ability to run at overload, and consequently a locomotive with polyphase motor will run up grade without serious loss of speed. The single phase system has been carried on on Swiss and Italian railroads, notably on the Simplon Tunnel and the Baltelina lines with great success, and the distribution problems are reduced to a minimum. In the United States a notable installation has been on the New York, New Haven & Hartford Railroad, where the section between Stamford and New York has been worked by electricity exclusively since July 1, 1908. Here the single phase motors use direct current while running over the tracks of the New York Central from Woodlawn to the Grand Central Terminal. On both the New York, New Haven & Hartford and the New York Central locomotives the armature is formed directly on the axle of the driving wheels, so consequently much interest attaches to the new design adopted for the Pennsylvania tunnels, where the armatures of the direct current motors are connected with the driving wheels by connecting rods somewhat after the fashion of the steam locomotive, and following in this respect some successful European practice.

## LIST OF BOOKS.

Thomson's *Elementary Lessons in Electricity and Magnetism.* Macmillan.
Thomson's Translation of Guillemin's *Electricity and Magnetism.* Macmillan.
Foster and Atkinson's Adaptation of Joubert's *Elementary Treatise on Electricity and Magnetism.* Longmans.
Mendenhall's *Century of Electricity.* Macmillan.
Jamieson's *Elementary Manual of Electricity and Magnetism.* Griffin.
Burch's *Manual of Electric Science.* Methuen.
Bottone's *Electricity and Magnetism.* Whittaker.
Stewart's *Text-book of Magnetism and Electricity.* Clive.
Pope and Brackett's *Electricity in Daily Life.* Kegan Paul.
Trevert's *Electricity and its Recent Applications.* Alabaster & Gatehouse.
Trevert's *Everybody's Handbook of Electricity.* Alabaster & Gatehouse.
*Electrical Apparatus for Amateurs.* Ward & Lock.
Gillett's *Phonograph, and How to Construct it.* Spon.
Ayrton's *Practical Electricity.* Cassells.
Fleming's *Short Lectures to Electrical Artisans.* Spon.
Slingo and Brooker's *Electrical Engineering.* Longmans.
Preece and Sievewright's *Telegraphy.* Longmans.
Preece and Stubbs' *Manual of Telephony.* Whittaker.
Poole's *Practical Telephone Handbook.* Whittaker.
Bottone's *Dynamo: How Made and How Used.* Sonnenschein.
Bottone's *Electro-motors: How Made and How Used.* Whittaker.
Wallis and Hawkin's *Dynamos.* Whittaker.
Allsop's *Induction Coils.* Spon.
Allsop's *Practical Electric Lighting.* Whittaker.
Bax's *Popular Electric Lighting.* Biggs.

Bottone's *Guide to Electric Lighting for Householders.* Whittaker.
Gordon's *Decorative Electricity.* Low.
Reckenzaum's *Electric Traction.* Biggs.
Gore's *Electro-Chemistry.* Electrician Co.
Benjamin's *Voltaic Cell.* Wiley, of New York.
Niblett's *Secondary Batteries.* Biggs.
Sloane's *Standard Electrical Dictionary.* Lockwood.
Maycock's *Practical Electrical Notes and Definitions.* Spon.
Trevert's *Electrical Measurements for Amateurs.* Alabaster & Gatehouse.
Southam's *Electrical Engineering as a Profession.* Whittaker.
Field's *Story of the Atlantic Cable.* Gay & Bird.

# APPENDIX.

## UNITS OF MEASUREMENT.

(*From Munro and Jamieson's Pocket-book of Electrical Rules and Tables*).

I. FUNDAMENTAL UNITS. — The electrical units are derived from the following mechanical units:—

The *Centimetre* as a unit of *length;*
The *Gramme* as a unit of *mass;*
The *Second* as a unit of *time.*

The *Centimetre* is equal to 0.3937 inch in length, and nominally represents one thousand-millionth part, or $\frac{1}{1000,000,000}$ of a quadrant of the earth.

The *Gramme* is equal to 15.432 grains, and represents the mass of a cubic centimetre of water at 4° C. Mass is the quantity of matter in a body.

The *Second* is the time of one swing of a pendulum making 86,164.09 swings in a sidereal day, or $\frac{1}{86,400}$ part of a mean solar day.

II. DERIVED MECHANICAL UNITS.—

*Area.*—The unit of area is the *square centimetre.*

*Volume.*—The unit of volume is the *cubic centimetre.*

*Velocity* is rate of change of position. It involves the idea of direction as well as that of magnitude. *Velocity* is *uniform* when equal spaces are traversed in equal intervals of time. The unit of velocity is the velocity of a body which moves through unit distance in unit time, or the *velocity of one centimetre per second.*

*Momentum* is the quantity of motion in a body, and is measured by mass × velocity.

*Acceleration* is the rate of change of velocity, whether that change take place in the direction of motion or not. The unit of acceleration is the acceleration of a body which undergoes unit change of velocity in unit time, or an acceleration of one centimetre-per-second per second. The acceleration due to gravity is considerably greater than this, for the velocity imparted by gravity to falling bodies in one second is about 981 centimetres per second (or about 32.2 feet per second). The value differs slightly in different latitudes. At Greenwich the value of the acceleration due to gravity is $g = 981.17$; at the Equator $g = 978.1$; at the North Pole $g = 983.1$.

*Force* is that which tends to alter a body's natural state of rest or of uniform motion in a straight line.

*Force* is measured by the acceleration which it imparts to mass — i. e., mass × acceleration.

*The Unit of Force*, or *Dyne*, is that force which, acting for one second on a mass of one gramme, gives to it a velocity of one centimetre per second. The force with which the earth attracts any mass is usually called the "weight" of that

mass, and its value obviously differs at different points of the earth's surface. The force with which a body gravitates—*i. e.*, its weight (in dynes), is found by multiplying its mass (in grammes) by the value of $g$ at the particular place where the force is exerted.

*Work* is the product of a force and a distance through which it acts. The unit of work is the work done in overcoming unit force through unit distance—*i. e.*, in pushing a body through a distance of one centimetre against a forch of one dyne. It is called the *Erg*. Since the "weight" of one gramme is $1 \times 981$ or 981 dynes, the work of raising one gramme through the height of one centimetre against the force of gravity is 981 ergs or $g$ ergs. One kilogramme-metre = 100,000 ($g$) ergs = $9.81 \times 10^7$ ergs. One foot-pound = 13,825 ($g$) ergs, = $1.356 \times 10^7$ ergs.

*Energy* is that property which, possessed by a body, gives it the capability of doing work. *Kinetic* energy is the work a body can do in virtue of its motion. *Potential* energy is the work a body can do in virtue of its position. The unit of energy is the *Erg*.

*Power or Activity* is the rate of work; the practical unit is called the *Watt* = $10^7$ ergs per second.

*A Horse-power* = 33,000 ft.-lbs. per minute = 550 ft.-lbs. per second; but as seen above under *Work*, 1 ft.-lb. = $1.356 \times 10^7$ ergs, and under *Power*, 1 *Watt* = $10^7$ ergs per sec. ∴ a *Horse-power* = $550 \times 1.356 \times 10^7$ ergs = 746 Watts;

$$\text{or,} \quad \frac{EC}{746} = \frac{C^2R}{746} = \frac{E^2}{746\ R} = \text{H.P.}$$

where E = volts, C = ampères, and R = ohms.

The French "*force de cheval*" = 75 kilogramme metres per sec. = 736 Watts = 542.48 ft.-lbs. per

sec. = ·9863 H.P.; or one H.P. = 1.01385 "*force de cheval.*"

*Derived Electrical Units*.—There are two systems of electrical units derived from the fundamental "C.G.S." units, one set being based upon the force exerted between two quantities of electricity, and the other upon the force exerted between two magnetic poles. The former set are termed *electro-static* units, the latter *electro-magnetic* units.

III. Electrostatic Units.—

*Unit quantity* of electricity is that which repels an equal and similar quantity at unit distance with unit force in air.

*Unit current* is that which conveys unit quantity of electricity along a conductor in a second.

*Unit electromotive force*, or *unit difference of potential* exists between two points when the unit quantity of electricity in passing from one to the other will do the unit amount of work.

*Unit resistance* is that of a conductor through which unit electromotive force between its ends can send a unit current.

*Unit capacity* is that of a condenser which contains unit quantity when charged to unit difference of potential.

IV. Magnetic Units.—

*Unit magnetic pole* is that which repels an equal and similar pole at unit distance with unit force in air.

*Strength of Magnetic Field* at any point is measured by the force which would act on a unit magnetic pole placed at that point.

*Unit Intensity of Field* is that intensity of field which acts on a unit pole with unit force.

*Moment of a Magnet* is the strength of either pole multiplied by the distance between the poles.

*Intensity of Magnetisation* is the magnetic moment of a magnet divided by its volume.

*Magnetic Potential.*—The potential at a point due to a magnet is the work that must be done in removing a unit pole from that point to an infinite distance against the magnetic attraction, or in bringing up a unit pole from an infinite distance to that point against the magnetic repulsion.

*Unit Difference of Magnetic Potential.*—Unit difference of magnetic potential exists between two points when it requires the expenditure of one *erg* of work to bring an (N. or S.) unit magnetic pole from one point to the other against the magnetic forces.

V. Electro-Magnetic Units.—

*Unit current* is that which in a wire of unit length, bent so as to form an arc of a circle of unit radius, would act upon a unit pole at the centre of the circle with unit force.

*Unit quantity* of electricity is that which a unit current conveys in unit time.

*Unit electro-motive force or difference of potential* is that which is produced in a conductor moving through a magnetic field at such a rate as to cut one unit line per second.

*Unit resistance* is that of a conductor in which unit current is produced by unit electro-motive force between its ends.

*Unit capacity* is that of a condenser which will

be at unit difference of potential when charged with unit quantity.

Electric and magnetic force varies inversely as the square of the distance.

## PRACTICAL UNITS OF ELECTRICITY.

Resistance—R.—The *Ohm* is the resistance of a column of mercury 106.3 centimetres long, 1 square millimetre in cross-section, weighing 14.4521 grammes, and at a temperature of 0° centigrade. Standards of wire are used for practical purposes. The ohm is equal to a thousand million, $10^9$, electromagnetic or Centimetre-Gramme-Second ("C. G. S.") units of resistance.

The *megohm* is one million ohms.

The *microhm* is one millionth of an ohm.

Electromotive Force—E.—The *Volt* is that electromotive force which maintains a current of one ampère in a conductor having a resistance of one ohm. The electromotive force of a Clark standard cell at a temperature of 15° centigrade is 1.434 volts. The volt is equal to a hundred million, $10^8$, C. G. S. units of electromotive force.

Current—C.—The *Ampère* is that current which will decompose 0.09324 milligramme of water ($H_2O$) per second or deposit 1.118 milligrammes of silver per second. It is equal to one-tenth of a C. G. S. unit of current.

The *milliampère* is one thousandth of an ampère.

Quantity—Q.—The *Coulomb* is the quantity of electricity conveyed by an ampère in a second. It is equal to one-tenth of a C. G. S. unit of quantity.

The *micro-coulomb* is one millionth of a coulomb.

Capacity—K.—The *Farad* is that capacity of a

body, say a Leyden jar or condenser, which a coulomb of electricity will charge to the potential of a volt. It is equal to one thousand-millionth of a C. G. S. unit of capacity.

The *micro-farad* is one millionth of a Farad.

By *Ohm's Law*, Current = Electromotive Force ÷ Resistance,

$$\text{or } C = \frac{E}{R}$$

$$\text{Ampère} = \frac{\text{Volt}}{\text{Ohm}}$$

Hence when we know any two of these quantities, we can find the third. For example, if we know the electromotive force or difference of potential in volts and the resistance in ohms of an electric circuit, we can easily find the current in ampères.

POWER—P.—The *Watt* is the power conveyed by a current of one ampère through a conductor whose ends differ in potential by one volt, or, in other words, the rate of doing work when an ampère passes through an ohm. It is equal to ten million, $10^7$, C. G. S. units of power or ergs per second, that is to say, to a Joule

per second, or $\frac{1}{746}$ of a horse-power.

A Watt = volt × ampère, and a Horse-power = Watts ÷ 746.

HEAT OR WORK—W.—The *Joule* is the work done or heat generated by a Watt in a second, that is, the work done or heat generated in a second by an ampère flowing through the resistance of an ohm. It is equal to ten million, $10^7$, C. G. S. units of work or ergs. Assum-

ing "Joule's equivalent" of heat and mechanical energy to be 41,600,000, it is the heat required to raise .24 gramme of water 1° centigrade. A Joule = Volt × ampère × second. Since 1 horse-power = 550 foot pounds of work per second,

$$W = \frac{550}{746} E.Q. = .7373 \text{ E.Q. foot pounds.}$$

## Heat Units.

The *British Unit* is the amount of heat required to raise one pound of water from 60° to 61° Fahrenheit. It is 251.9 times greater than the metric unit, therm or calorie, which is the amount of heat required to raise one gramme of water from 4° to 5° centigrade.

*Joule's Equivalent*—J.—is the amount of energy equivalent to a therm or calorie, the metric unit of heat. It is equal to 41,600,000 ergs.

The heat in therms generated in a wire by a current = Volt × ampère × time in seconds × 0.24.

## Light Units

The *British Unit* is the light of a spermaceti candle $^7/_8$-inch in diameter, burning 120 grains per hour (six candles to the pound). They sometimes vary as much as 10 per cent. from the standard. Mr. Vernon Harcourt's standard flame is equal to an average standard candle.

The *French Unit* is the light of a Carcel lamp, and is equivalent to $9^1/_2$ British units.

# INDEX.


A.

Amber, 9.
Ampère, 76, 220.
Accumulator, 39.
  E. P. S., 40.
  Faure, 39.
  Grove gas, 39.
  Planté, 39.
  Sellon-Volckmar, 40.
Appendix, 215.
Arc, electric, 110, 122.

B.

Books, list of, 213.

C.

Capacity, 220.
Coal, electricity from, 131.
Code, Morse telegraph, 87, 101.
Compass, mariner's, 46.
Condenser, 62.
Conduction, 16.
Conductors, 16.
Coulomb, 76, 220.
Current, electric, 57.
  attraction of, 57.
  electromotive force of, 74.
  Ohm's law for, 76.
  potential of, 75.
  pressure of, 74.
Currents, electric, resistance of, 74, 75.
  rules for direction of, 56, 65, 66.

D.

Diamagnetism, 51.
Dynamos, 67.
Dynamos, compound, 73.
  Gramme, 69.
  magneto-electric, 67.
  reversibility of, 65, 73.
  series, 70.
  shunt, 71.

E.

Electric alarms, 146.
  burglar, 148.
  fire, 147.
  frost, 149.
  torpedo, 149.
  water, 149.
Electric arc, 110.
  arc lamps, 111.
  bell, 143.
  boat, 128.
  carriage, 128.
  chronograph, 151.
  circuits, 118.
  city, 132.
  clocks, 150.
  compass, 150.
  cooking, 123.
  cut-outs, 120.
  divining rod, 155.
  drill, 133.
  fishes, 163.
  forces, 11.
  furnace, 122, 191.
  fuse, 163.
  gaslighter, 160.
  heat, 122.
  incandescent lamps, 123.
  induction glows, 120.
  lamp-lighter, 162.
  light signals, 152.
  log, 149.
  meters, 152.
  motor, 73.

Electric pen, 156.
power, 124.
power, transmission of, 125.
quilt, 124.
radiator, 124.
railway, 126, 205.
search light, 153.
sewing machine, 132.
shock, treatment for, 163.
silhouettes, 167.
torpedo, 130.
traction, 203.
tramway, 126.
tricycle, 128.
ventilator, 130.
weather vane, 150.
welding, 122.
Electricity, chemistry and, 26.
coal and, 131.
friction and, 9.
heat and, 41.
magnetism and, 45.
Niagara and, 132.
origin of the science, 10.
peat and, 131.
scale of bodies producing, 14.
surface, 17.
Electro-cautery, 162.
Electro-chemical equivalent, 77.
Electro-chemistry, 26, 187.
Electro-deposition of metals, 77.
Electrolysis, 74.
Electromagnet, 60.
Electromagnetism, 59.
Electromedicine, 163.
Electro-metallurgy, 187.
Electromotive force, 29, 74.
Electrophorus, 20.
Electroplating, 78.
Electrotyping, 80.
Energy, 217.

F.

Farad, 220.

G.

Galvanism, discovery of, 26.
Galvanometer, 56.
Galvanoscope, 56.
Geissler tubes, 63, 168.

H.

Heat, 41, 222.
unit, 218.
Hysteresis, magnetic, 53.

I.

Induction, 18.
balance, 154.
Induction coil, 61.
magneto electric, 154.
magneto, direction of current, 56, 66.
Inductive capacity, 20.
Insulation, 16.
Insulators, 16.
Ion, 76.

J.

Joule, 221.
Joule's equivalent, 222.

L.

Leyden jar, 21.
Light, unit, 222.
Lightning, nature of, 25.
rods, 25.
rod testing, 164.
shock, treatment for, 163.
Lodestone, 46.

M.

Magnet, horse-shoe, 54.
natural, 47.
Magnetic compass, origin of, 46.
Magnetic lines of force, 54, 57.
Magnetism, 45.
connection with electricity, 55.
earth's, 49.
earth's forces of, 50.
earth's theory of, 52.
Magnetite, 46.
Measurement, units of, 215.
Microphone, Hughes', 104.
Morse code, 87.
telegraph, 88.
Motor, electric, 73.

N.

Niagara, electricity from, 132, 187, 198.

O.

Ohm, 76, 220.
Ohm's law, 76, 221.

P.

Paramagnetism, 51.
Peat, electricity from, 131.

Peltier effect, 45.
Phonograph, 156.
Photo-electric cell, 154.
Photophone, 153.
Power, 217.
Pressure of a current, 74.
Primary cells, 37.
  coils, 61.
  current, 61.

R.

Resistance, 30.

S.

Secondary cells, 37.
  coils, 61.
  currents, 61.
Shocks, electric, 163.
Sonometer, 155.
Sounder, 90.
Storage cell, 37.
Submarine cable, 95.
  Atlantic, 96.
  circuit, 98.
  mirror instrument, 99.
  signal alphabet, 101.
  siphon recorder, 100.
  speed of messages, 101.
  detector, 155.

T.

Telautograph, 93.
Telegrams, errors in, 92.
Telegraph, automatic sender, 92.
  chemical, 90.
  circuit, 84.
  C. M.'s, 24.
  Cooke and Wheatstone, 82.
  domestic, 150.
  duplex system, 92.
  Hughes, 91.
  Kelvin, 99.
  Morse, 88.
  origin of, 81.
  Ronald's 24.
Telegraph, Vail, 90.
  wireless, 174.
Telephone, Bell, 102.
  cable, 107.
  Chicago to New York, 107.
  Edison, 103.
  exchange, 107.
  instrument of Blake, 107.
  switchboard, 108.
Thermo-electricity, 41.
Thermo-electric couple, 41.
  in series, 43.
  piles, 44.
  scale, 42.

U.

Units, 215.

V.

Volt, 76, 220.
Voltaic cell, 27.
  action of, 28.
  bichromate, 28.
  Bunsen, 33.
  Chloride of silver, 35.
  Clark Standard, 36.
  Coupling, 31.
  Daniell, 32.
  Dry "E. C. C.," 36.
  Grove, 33.
  Grove gas, 39.
  Hellesen, 37.
  Leclanché, 34.
  Leclanché-Barbier, 37.
  Schanschieff, 36.
  Skrivanoff, 36.
  Smee, 33.
Voltaic electricity, discovery of, 27.
Voltameter, 38.

W.

Water, decomposition of, 37.
Watt, 221.
Wheatstone bridge, 164.
Wireless telegraph, 174.
Work, 183, 221.

THE END.

49 U 618 (2)

LIBRARY OF CONGRESS

0 003 708 131 0